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Strategies for Energy Conservation for A School Building

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, DC 20234

March 1984

Prepared for
Office of Building Energy Research and Development
Office of Conservation and Renewable Energy
U.S. Department of Energy
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STRATEGIES FOR ENERGY CONSERVATION FOR A SCHOOL BUILDING

James Y. Kao

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
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ABSTRACT

A comparative analysis is made of the thermal performance of selected HVAC systems and control strategies commonly employed in education buildings. The comparisons are made for six geographical locations representing wide climatic variations within the continental United States.

Hour-by-hour simulations with the BLAST computer program are used to obtain the yearly heating, cooling, and fan energy consumption of an elementary school. The HVAC systems simulated are constant volume reheat, variable air volume, dual-duct, and unit ventilator systems. The control strategies tested are dry-bulb temperature economy cycle, enthalpy economy cycle, supply air temperature resetting, and the combinations of these strategies. The results of these simulations are presented and discussed. Substantial energy consumption differences are shown to exist.

Key words: school building control strategies; school building energy conservation; school HVAC systems; school building thermal performance.

PREFACE

This report is one of a series documenting NBS research and analysis efforts in developing energy and cost data to support the Department of Energy/National Bureau of Standards Building Energy Conservation Criteria Program. The work reported in this document was performed under the Energy Analysis of Control Strategies project, a part of the controls program element managed by Building Systems Division, Office of Building Energy Research and Development, U.S. Department of Energy. The NBS effort was supported by DoE/NBS Task Order A008-BCS under Interagency Agreement No. EA77A 01-6010.

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1. INTRODUCTION

This report is the fourth and last in a series of reports by researchers at the National Bureau of Standards (NBS) which compare the energy consumption of alternative heating, ventilating, and air-conditioning (HVAC) systems and control strategies for commercial and institutional buildings. The purpose of this report, along with the three previous reports which studied a small office building [1]*, a large retail store [2], and a large office building [3], was to generate comparative energy consumption data for various building types in different geographical locations in the United States. These studies were intended to derive general guidelines of air handling system control strategy selections for building operators and designers. The results and conclusions of these studies should aid the prospective users in making preliminary decisions about strategies for air-handling system controls in both new and renovative work. The present study specifically deals with an education building. Although a large elementary school was used as the building sample, the study results should be applicable to high school buildings of similar construction and usage. The air handling systems and control strategies employed in this study were those most commonly used for this type of building.

The energy program used in this study was the Building Loads Analysis and System Thermodynamics Program (BLAST, Version 2.0) [4]. The cities used for the energy simulations in the present series of reports [including 1, 2, and 3] were Lake Charles, Louisiana; Madison, Wisconsin; Nashville, Tennessee; Santa Maria, California; Seattle, Washington; and Washington, D.C. These cities range from approximately 1500 to 8000 heating degree days (65°F base) and from 100 to 3000 cooling degree days (65°F base), and represent a wide variety of climatic conditions in the United States.

The energy consumption results of this study were limited to the energy consumed by the air-handling systems. For the readers who are interested in comparing the dollar cost of different systems and control strategies, it is necesary to modify the present data with energy transmission losses, plant efficiencies, and energy costs.

Since the BLAST-2 program is an hourly energy program, the energy effect caused by the dynamics of the control component interactions may not be included in the energy consumption results. The size of this effect, which may be significant, was not investigated in this study.

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* See references at end of text.

2. ENERGY SIMULATION

2.1 BUILDING MODEL AND WEATHER DATA

The modeled building was a one-story elementary school. The total gross floor area was approximately 59,300 square feet (5,509 m^2). The classrooms, library, and offices were located on the eastern part of the building. The non-classroom/office areas, such as auditorium, cafeteria, kitchen, and gymasium, were situated on the western part. There were 22 classrooms with a total floor area of 21,500 square feet (1,997 m^2). The total floor area of the offices was 6,400 square feet (5,946 m^2). The school population, including faculty and students, was 860. The building dimensions, space arrangement, and other pertinent building construction data are shown in figure 1.

The weather data used for the simulations were from the Typical Meteorological Year (TMY) climatic tapes [5].

2.2 AIR HANDLING SYSTEM SIMULATION AND CONTROL STRATEGIES

The capacities of the air handling systems were sized to keep the space temperature between 68°F (20.0°C) and 78°F (25.6°C) during occupied hours. ASHRAE [6] 97.5 percent design dry-bulb temperature and 2.5 percent design dry-bulb/mean coincidence wet-bulb temperature were used in sizing system calculations. The night and weekend heating setback temperature was 55°F (12.8°C). The air handling system fans ran continuously during occupied hours and ran intermittently during setback hours. It was assumed that both the cooling and heating media (chilled and hot water) were available year-round. The throttling range[1/] of the cooling coil controller was 3°F (1.7°C).

The daily occupancy, lighting, and equipment (in cafeteria) loadings and profiles of the various spaces are shown in figures 2 through 6. At least 5 cfm (2.36×10^{-3} m^3/s) per person of outside air was used for ventilation calculations. The kitchen had a total exhaust of 12 air changes per hour with the make-up air coming from a heating and ventilating unit, the cafeteria and the halls.

Since the classrooms, offices, and the library were concentrated in the east and central part of the building, they were simulated by using either two large air handling systems or individual cooling type unit ventilators in each space. The non-classroom/office spaces -- auditorium, cafeteria, kitchen, and gymnasium -- were each supplied by an individual air handling system. These non-classroom/office spaces, with the exception of the kitchen, were air conditioned by single-zone draw through systems having both heating and cooling coils. The only control strategy used for these systems was the enthalpy economy cycle. A heating and ventilating unit was provided for the kitchen heating

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1/ Throttling range is defined as the change required, in a proportional system, in a controlled variable (such as air temperature) to move the controlled device (such as a coil valve) from one of its extreme positions of travel to the other (such as from fully open to fully closed).

and exhaust requirement. The classroom and office area were simulated by four types of air handling systems commonly used for the schools. They were the constant volume reheat, variable air volume, dual-duct, and cooling type unit ventilators. The control strategies tested for the classroom area included outside air economy cycles (both dry-bulb and enthalphy comparisons), cold and hot air temperature reset and combination of these strategies. In one case (case 16), the air handling systems were in continuous operation for 10 hours a day. In all the other cases, the air handling systems were in continuous operation only during occupied hours. The energy consumption was simulated for the entire year, although for most schools recess took place during summer and Christmas periods. Details of the HVAC systems and control strategies are given in the following paragraphs. Cases 1 through 15 are for classrooms, offices and the library. Case 16 through 27 are for the entire school.

A. Case 1 -- Base Reheat (RH) System

Constant volume terminal reheat systems were used for the classroom, offices, and library. The supply air temperature was 59°F (15.0°C) which included the fan heat gain. The amount of outside air was held constant at 20 percent of the total supply air. The system serving the classrooms was in continuous operation 7 hours a day. The system that supplied air to the library and offices was in continuous operation 10 hours a day. The total pressure of the supply air fans and return air fans were assumed to be 3.5 in. of water (8.7×10^2 Pa) and 0.5 in. of water (1.2×10^2 Pa), respectively. Their efficiencies were assumed to be 75 percent.

B. Case 2 -- Reheat (RH) System with Temperature Economy Cycle

Temperature economy cycle was added to case 1. The mixed air temperature of the return and outside air streams was maintained by modulating the dampers to satisfy the supply air sensor setting. When the outside air temperatures rose to above the setting of this sensor, the outside air damper was closed to its minimum position of 20 percent of the supply air and the building cooling was accomplished entirely by the chilled water.

C. Case 3 -- Reheat (RH) System with Enthalpy Economy Cycle

Enthalpy economy cycle was added to case 1. When the enthalpy of the outside air was lower than that of the return air, the full amount of outside air was admitted to the system, provided the temperature of the mixed air was not below the temperature setting of the supply air. Otherwise, only the minimum amount of outside air was admitted. This comparison was accomplished by having enthalpy sensors in the return and outside air streams.

D. Case 4 -- Reheat (RH) System with Supply Air Temperature Reset by Zone Load Demand

Case 1 was modified to have variable supply air temperature. Zone temperature sensors were simulated to reset the supply air temperature higher than 59°F (15°C) as determined by the zone having the highest cooling load. The supply air temperature was limited to between 59°F (15°C) and 65°F (18.3°C).

E. Case 5 -- Reheat (RH) System with Enthalpy Economy Cycle and Supply Air Temperature Reset by Zone Load Demand

This case combined cases 3 and 4.

F. Case 6 -- Base Variable Air Volume (VA) System

Variable air volume systems with terminal reheat coils were simulated for the classrooms, offices and library. Terminal units for the perimeter zones were provided with reheat coils. The minimum supply air of the terminal units were set at 0.5 and 0.2 of the peak suppy air for classrooms and offices (including library), respectively. The supply air fan pressure was assumed to be 4.0 in. of water (1.0 x 10^3Pa) and inlet vanes were used for capacity throttling. The supply air temperature was 59°F (15°C), the same as for the reheat system.

G. Case 7 -- Variable Air Volume (VA) System with Temperature Economy Cycle

Temperature economy cycle was added to case 6.

H. Case 8 -- Variable Air Volume (VA) System with Enthalpy Economy Cycle

Enthalpy economy cycle was added to case 6.

I. Case 9 -- Variable Volume (VA) System with Supply Air Temperature Reset by Zone Load Demand

The supply air temperature was allowed to vary between 59°F (15°C) and 65°F (18.3°C) similar to the reheat system of case 4.

J. Case 10 -- Variable Air Volume (VA) System with Enthalpy Economy Cycle and Supply Air Temperature Reset by Zone Load Demand

This case combined cases 8 and 9.

K. Case 11 -- Base Dual-Duct (DD) System

Dual-duct systems were used for the classrooms, offices and library. The dual-duct systems had preheat coils in the mixed air stream with the main heating and cooling coils in the hot and cold ducts. The cold air temperature was set at 59°F (15°C) and the hot air temperature was set at 120°F (48.9°C). The supply air fan pressure was assumed to be 4 in. of water (1.0 x 10^3Pa). The air flow rates of the supply air and return air fans were the same as those of the reheat system. The energy losses from mixing damper leakage were not considered in this case and the other dual-duct cases.

L. Case 12 -- Dual- Duct (DD) System with Enthalpy Economy Cycle

Enthalpy economy cycle was added to case 11.

M. Case 13 -- Dual-Duct (DD) System with Enthalpy Economy Cycle and Hot Air Temperature Reset

The hot air temperature of the dual-duct systems were reset by the outside temperature. When the outside air temperature was 0°F (-17.8°C) and below, the hot air temperature was 120°F (48.9°C) and when the outside air temperature was 70°F (21.1°C) and higher, the hot air temperature was 90°F (32.2°C). The hot air temperature varied between 120°F (48.9°C) and 90°F (32.2°C) according to the outside air temperature. Other than this reset schedule, the systems operated the same as those of case 12.

N. Case 14 -- Dual-Duct (DD) System with Fixed Outside Air and Reset of Both Hot and Cold Air Temperature

The systems had fixed ventilation air during occupied hours. The hot air temperature was reset as described in case 13 and the cold air temperature was reset between 59°F (15°C) and 65°F (18.3°C) to satisfy the highest cooling load zones.

O. Case 15 -- Unit Ventilator (UV) System with Cooling

The thermal zones for the classrooms, offices, and library were simulated with cooling type unit ventilators. The unit ventilators had heating and cooling available year-round. The outside air dampers were capable of admitting 100 percent outside air. Room temperature sensors controlled the heating coil valves, the dampers, and the cooling coil valves to maintain the space temperature.

P. Case 16 -- Case 1 for Classrooms and Offices, Draw-Through Systems with Minimum Ventilation Air for Non-classroom/office Spaces -- All Systems On for 10 Hours a Day

As described previously, the non-classroom/office spaces which included the auditorium, cafeteria, kitchen, and gymnasium, had draw-through type units. The kitchen system had no cooling capability and its outside air dampers were fully open when the system was on. All other systems served the auxiliary spaces had cooling coils to supply a fixed air temperature of 59°F (18.3°C). All systems in this case ran 10 hours a day regardless of their occupancy schedules.

Q. Case 17 -- Case 1 for Classrooms and Offices, Draw-Through Systems with Minimum Ventilation Air for Non-classroom/office Spaces (Base) -- All Systems On According to their Occupancy Schedules

This case was similar to case 16 above except that the system operation schedules during school days followed the individual occupancy schedules of the spaces. The classroom, office (including library), auditorium, cafeteria and kitchen, and gymnasium systems were operating 7, 10, 3, 6, and 7 hours, respectively. This case is used as the base case in tables 7 through 12 for comparing the energy consumption of the entire school.

R. <u>Case 18 -- Case 3 for Classrooms and Offices, Enthalpy Economy Cycle Added to Systems Serving Non-classroom/office Spaces</u>

The base reheat systems of the classrooms and offices were combined with the non-classroom/office systems, all under enthalpy economy cycles.

S. <u>Case 19 -- Case 5 for Classrooms and Offices, Enthalpy Economy Cycles Added to Systems Serving Non-classroom/office Spaces</u>

The classroom and office reheat systems with supply air temperature reset were combined with the non-classroom/office systems, all under enthalpy economy cycle.

T. <u>Case 20 -- Case 6 for Classrooms and Offices, Base Systems for Non-classroom/office Spaces</u>

The classroom and office base variable air volume systems were combined with the non-classroom office systems.

U. <u>Case 21 -- Case 8 for Classrooms and Offices, Enthalpy Economy Cycle Added to Systems Serving Non-classroom/office Spaces</u>

The classroom and office variable air volume systems were combined with the non-classroom/office systems, all under enthalpy economy cycle.

V. <u>Case 22 -- Case 10 for Classrooms and Offices, Enthalpy Economy Cycle Added to Systems Serving Non-classroom/office Spaces</u>

The classroom and office variable air volume systems with supply air temperature reset were combined with the non-classroom/office systems, all under enthalpy economy cycle.

W. <u>Case 23 -- Case 11 for Classrooms and Offices, Base System for Non-classroom/office Spaces</u>

The classroom and office base dual-duct systems were combined with the non-classroom/office systems.

X. <u>Case 24 -- Case 13 for Classrooms and Offices, Enthalpy Economy Cycle Added to Systems Serving Non-classroom/office Spaces</u>

The classroom and office dual-duct systems with hot air temperature reset were combined with the non-classroom/office systems, all under enthalpy economy cycle.

Y. <u>Case 25 -- Case 14 for Classrooms and Offices, Enthalpy Economy Cycle Added to Systems Serving Non-classroom/office Spaces</u>

The classrooms and office dual-duct system with hot and cold air temperature reset were operated with the minimum amount of ventilation air. The systems

serving the non-classroom/office spaces were operated under enthalpy economy cycle.

Z. Case 26 -- Case 15 for Classrooms and Offices, Enthalpy Economy Cycle Added to Systems Serving Non-classroom/office Spaces

The classrooms and offices were simulated with individual cooling type unit ventilators as described in case 15. The systems serving the non-classroom/office spaces were operated under enthalpy economy cycle.

3. RESULTS AND DISCUSSION

3.1 ENERGY CONSUMPTION RESULTS

The yearly energy consumption for heating, cooling, and fan operation resulting from diferent systems, strategies, and combination of strategies is listed for each of the six cities in tables 1 through 6. Table 7 through 12 give the yearly heating, cooling, and fan energy consumption per unit floor area based on the gross floor area of the systems served. Tables 7 through 12 also give the comparative energy consumption data normalized to the consumption of a base case. Cases 1 through 15 are for classrooms and offices (including library) only and the base reheat systems (case 1) is used as the base case. Cases 16 through 26 are for the entire school and case 17 is used as the base case. As described previously, case 17 had reheat systems for the classrooms and offices (including library) and single-zone, draw-through type systems for the non-classroom/office spaces, all operated according to the space occupancy schedules.

The yearly cooling and heating energy consumption results are also plotted against the cooling and heating degree days in figures 8 through 38. The reasons for using the 65°F (18.3°C) base degree days was given in references 2 and 3. The cooling and heating energy consumption data points of each case are fitted with a least-squares line. Figures 8 through 12 show the classroom and office area under the reheat systems. Figure 13 is a comparison of figures 8 through 12. Figures 14 through 18 and figures 20 through 23 are for variable air volume systems and dual-duct systems, respectively. Figures 19 and 24 show the various control strategies applied to these two systems, respectively. Figure 25 shows the energy consumption of unit ventilators for the classrooms and offices. Figure 26 puts four cases together for comparison--one case for each of the four systems. Figure 27 through 37 show the yearly cooling and heating energy consumption of cases 16 through 26 of the entire school. Figure 38 has cases 16 and 17 together on the same charts to compare the energy consumption of the entire school when the air-handling systems were operating under different schedules.

3.2 COMPARISON OF STRATEGIES

A. Outside Air Economy Cycles

Two outside air economy cycles were applied to the reheat and variable air volume systems. The temperature economy cycle mixed the outside air and return air in order to maintain the temperature of the supply air setting. The enthalpy economy cycle compared the enthalpies of the outside air and return air to admit the minimum amount of ventilation air only when the outside air enthalpy was higher than that of the return air. Otherwise the outside air damper position was so determined that the mixed air temperature would not fall below the supply air temperature setting. The dual-duct system used for the classrooms and offices, and the single-zone draw-through systems used for the non-classroom/office spaces were also simulated with enthalpy economy cycle. The table lists the annual energy consumption ratios of various economy cycles of the six cities.

Table Showing Cooling and Heating Energy Consumption Ratios of Economy Cycles

	Lake Charles	Madison	Nashville	Santa Maria	Seattle	Washington, DC
Cooling Degree Days	2739	460	1694	84	129	1415
RH with Temperature Economy (Case 2)/Base RH (Case 1), Classrooms & Offices						
Cooling	0.92	0.68	0.80	0.87	0.52	0.73
Heating	1.02	1.02	1.02	1.02	1.02	1.02
RH with Enthalpy Economy (Case 3)/Base RH (Case 1), Classrooms & Offices						
Cooling	0.85	0.53	0.69	0.46	0.25	0.61
Heating	1.03	1.02	1.01	1.07	1.03	1.03
VA with Temperature Economy (Case 7)/Base VA (Case 6), Classrooms & Offices						
Cooling	0.98	0.93	0.95	0.92	0.72	0.92
Heating	1.01	1.00	1.00	1.01	1.00	1.00
VA with Enthalpy Economy (Case 8)/Base VA (Case 6), Classrooms & Offices						
Cooling	0.94	0.80	0.88	0.56	0.41	0.84
Heating	1.02	1.00	1.01	1.03	1.00	1.00
DD with Enthalpy Economy (Case 12)/Base DD (Case 11), Classrooms & Offices						
Cooling	0.86	0.56	0.71	0.46	0.26	0.63
Heating	1.15	1.10	1.17	1.27	1.15	1.15
RH with Enthalpy Economy (Case 18)/Base RH (Case 17), Entire School						
Cooling	0.86	0.55	0.71	0.47	0.26	0.63
Heating	1.03	1.02	1.03	1.06	1.05	1.03
VA with Enthalpy Economy (Case 21)/Base VA(Case 20), Entire School						
Cooling	0.94	0.81	0.89	0.56	0.43	0.86
Heating	1.01	1.00	1.00	1.02	1.01	1.00

RH = reheat
VA = variable air volume
DD = dual-duct

In almost all cases, the percentage of cooling energy savings were higher in low cooling degree day areas, such as Seattle, Santa Maria, and Madison. The only exception was in Santa Maria, when temperature economy cycle was applied to reheat systems (case 2 vs case 1), more cooling savings were achieved in Washington, D.C. and Nashville than that of Santa Maria. This was caused by the low setting of the 59°F (15°C) discharge air temperature which eliminated a larger portion of the available free-cooling time in Santa Maria. The percentage of heating energy increase caused by the economy cycles were rather small, except for the dual-duct cases. This small increase of heating energy was quite different from the results of other type of buildings [1, 2, 3]. This

phenomenon can be traced to the heavy internal load of the classrooms which reduced the heating energy consumed and benefitted from the free-cooling of the economy cycles. The results also indicated that the percentage reduction of cooling energy in variable air volume systems (cases 7 and 8 vs case 6) were not as prominent as in other systems.

In comparing temperature economy strategy with enthalpy economy strategy, it is also true that the lower cooling degree day areas benefitted more from enthalpy economy cycles than the other ciities. This may be seen from the following table.

Table Comparing Cooling and Heating Energy Consumption Ratios of Enthalpy and Temperature Economy Cycles

	Lake Charles	Madison	Nashville	Santa Maria	Seattle	Washington, DC
Cooling Degree Days	2739	460	1694	84	129	1415
RH with Enthalpy (Case 3)/with Temperature (Case 2), Classrooms & Offices						
Cooling	0.92	0.79	0.85	0.53	0.48	0.84
Heating	1.02	1.01	1.01	1.06	1.01	1.01
VA with Enthalpy (Case 8)/with Temperature (Case 7), Classrooms & Offices						
Cooling	0.96	0.86	0.93	0.61	0.57	0.91
Heating	1.01	1.00	1.00	1.03	1.01	1.00

RH = reheat
VA = variable air volume

B. Supply Air Temperature Reset

The following table compares the energy consumption results of the temperature reset cases.

Table Showing Cooling and Heating Energy Consumption Ratios of Reset Strategies

	Lake Charles	Madison	Nashville	Santa Maria	Seattle	Washington, DC
Cooling Degree Days	2739	460	1694	84	129	1415
Heating Degree Days	1498	7730	3696	3053	5185	4211
RH System (Case 4)/Base RH (Case 1), Classrooms & Offices						
Cooling	0.79	0.63	0.73	0.68	0.63	0.69
Heating	0.56	0.80	0.66	0.58	0.71	0.71
RH System with Enthalpy Economy Cycle (Case 5)/Base RH (Case 1), Classrooms & Offices						
Cooling	0.67	0.35	0.50	0.22	0.12	0.43
Heating	0.55	0.82	0.69	0.63	0.73	0.73
VA System (Case 9)/Base VA (Case 6), Classrooms & Offices						
Cooling	0.94	0.88	0.91	0.72	0.70	0.89
Heating	0.69	1.01	0.92	0.44	0.97	0.97
VA System with Enthalpy Economy Cycle (Case 10)/Base VA (Case 6), Classrooms & Offices						
Cooling	0.87	0.66	0.79	0.31	0.25	0.74
Heating	0.69	1.01	0.92	0.46	0.97	0.97
DD System with Enthalpy Economy Cycle and Hot Air Reset (Case 13)/DD System with Enthalpy Economy Cycle (Case 12), Classrooms & Offices						
Cooling	0.77	0.65	0.75	0.51	0.60	0.71
Heating	0.52	0.91	0.92	0.72	0.92	0.84
DD System Hot & Cold Air Reset (Case 14)/Base DD (Case 11), Classrooms & Offices						
Cooling	0.72	0.57	0.66	0.53	0.55	0.62
Heating	0.23	0.77	0.53	0.29	0.57	0.63

RH = reheat
VA = variable air volume
DD = dual-duct

Cases 4 and 9 were single strategy cases for reheat and variable air systems respectively. The supply air temperature was reset by the thermal zones of the highest cooling demand. Case 14 was for dual-duct system. The cold air temperature was reset by cooling demand and the hot air was reset by the outside air temperature. In comparing these three cases with their corresponding base systems (cases 1, 6, and 11), the cities having lower cooling degree days also had more cooling energy reduction (in percentages) than the cities having higher degree days. This reflected the skewed temperature distribution pattern which showed more hours in the higher temperature ranges for the high cooling degree day areas of this study. When the reset strategy was combined with the economy

cycles (cases 5, 10, and 13), more energy reduction was achieved. In every case the percentage reduction in heating energy was less in areas of higher heating degree days.

C. Unit Ventilation Systems

Unit ventilators have long been used in schools. The flexibility of both individual room temperature control and damper operation make them suitable for classroom use. The unit ventilator simulated in this study had wall thermostats for temperature modulation. Therefore, the spaces had no humidity control. The table below compares the yearly energy consumption of unit ventilator system with the other systems. The reheat (case 5) and variable air volume (case 10) had both enthalpy economy cycles and supply air temperature reset. The dual-duct system (case 14) had hot and cold air temperature only. The unit ventilators saved more cooling energy than the dual-duct systems in all six cities. They wasted more cooling than the variable air volume cases. When compared with the reheat system, the unit ventilators saved energy in low cooling degree days cities and wasted energy in other cities. The constant air flow rate during partial cooling period caused the unit ventilators to use more cooling energy than the variable air volume systems. The biggest savings of the unit ventilators were for heating. It was obvious that the high internal load of classrooms required little heating and the unit ventilators matched the heating load well.

Table Comparing Cooling and Heating Energy Ratios of RH, VA, DD, and UV Systems

	Lake Charles	Madison	Nashville	Santa Maria	Seattle	Washington, DC
Cooling Degree Days	2739	460	1694	84	129	1415
Heating Degree Days	1498	7730	3696	3053	5185	4211
RH vs UV (Case 5/Case 15), Classrooms & Offices						
Cooling	1.11	1.00	1.03	0.79	0.66	1.03
Heating	*	4.25	*	*	*	*
VA vs UV (Case 10/Case 15), Classrooms & Offices						
Cooling	0.88	0.68	0.81	0.40	0.38	0.78
Heating	*	3.21	*	*	*	*
DD vs UV (Case 14/Case 15), Classrooms & Offices						
Cooling	1.05	1.34	1.17	1.58	2.48	1.26
Heating	*	3.54	*	*	*	*

* more than 5.

RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

D. Fan Energy Consumption

The fan energy consumption ratios of some selected cases are listed in the following table for comparison. A base value of 1 is used for the reheat case. When the supply air temperature was reset in the variable air volume system, the fans consumed between 1 percent and 9 percent higher than without reset (based on reheat system consumption). The dual-duct system had 9 percent to 13 percent more than the reheat system. This was caused by the added 0.5 in. of water (1.2×10^2Pa) pressure for the mixing boxes. Obviously, the best systems were variable air volume and unit ventilator systems. It should be noted here that the fan energy consumption of the simulations were based on a set of assumed pressure requirements which were given in section 2.2.

Table Showing Fan Energy Consumption Ratios As Compared to RH System

	Lake Charles	Madison	Nashville	Santa Maria	Seattle	Washington, DC
RH (Case 5)	1.00	1.00	1.00	1.00	1.00	1.00
VA, No Temp. Reset (Case 8)	0.61	0.54	0.57	0.54	0.55	0.56
VA, with Temp. Reset (Case 10)	0.70	0.56	0.63	0.55	0.56	0.60
DD (Case 14)	1.12	1.11	1.10	1.13	1.09	1.10
UV (Case 15)	0.62	0.43	0.50	0.63	0.44	0.45

RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

E. System Operation Schedule

The air handling system operating schedules of all the simulations, except case 16, were based on space occupancy schedules. The system operating schedules were given in paragraph Q of section 2.2. Case 16 had all air handling systems operated 10 hours a day regardless of the occupancy schedule. The following table shows the annual cooling, heating, and fan energy consumption ratios of 10 hour operation to individual scheduled operations (case 16 vs case 17). Both cases were for the entire school operated under the same systems and control strategies.

Table Showing Energy Consumption Ratios of 16 hour/day to 10 hour/day Operation

	Lake Charles	Madison	Nashville	Santa Maria	Seattle	Washington, DC
Cooling Degree Days	2739	460	1694	84	129	1415
Heating Degree Days	1498	7730	3696	3053	5185	4211
Cooling	1.35	1.28	1.33	1.31	1.29	1.31
Heating	2.14	1.12	1.40	1.48	1.29	1.27
Fan	1.43	1.14	1.28	1.39	1.31	1.21

4. SUMMARY AND CONCLUSIONS

The comparative energy consumption of different air-handling systems was simulated for a large elementary school building. This simulation was performed for six cities representing various climatic conditions of the United States. These cities have 65°F based heating and cooling degree days which range from 1498 to 7730 for heating and from 84 to 2739 for cooling. The air handling systems simulated in the study included reheat, variable air volume, dual-duct and unit ventilator systems. The control strategies studied included two economy cycles (temperature and enthalpy), two supply air temperature resettings (by outside air temperature and by zone load demand), and the combination of these strategies. Comparisons were also made for air-handling system operating schedules.

The total yearly energy consumption results for the different cities simulated are presented in tables 1 through 6. The yearly energy consumption per unit floor area and the relative comparisons are shown in tables 7 through 12. Figures 8 through 38 depict these results correlated with cooling and heating degree days.

Listed below are some of the major conclusions which can be drawn for this school building, based on the parameters used in the study.

A. Based on the comparison of cooling energy consumption alone, the enthalpy cycle saved more than the temperature economy cycle. Generally, more savings in percentages predicted for the cities having lower cooling degree days. See paragraph A of section 3.2 for comparative values of these savings.

B. For most cities studied, the classrooms and offices had less than 3 percent heating energy increase when economy cycles were applied to reheat and variable air volume systems. Therefore, economy cycles were particularly suitable for school buildings with these types of air handling systems. Dual-duct systems for the classrooms and offices had higher heating energy consumption ranging between 10 and 27 percent when compared with systems without enthalpy economy cycle.

C. Resetting of cold and hot supply air temperature reduced air handling system energy consumption considerably. The energy reduction data are given in paragraph B of section 3.2. The cities of lower cooling degree days benefitted more in cooling energy reduction than higher degree day cities. The heating energy reduction in higher heating degree day areas were not as prominent as in lower heating degree day cities.

D. The energy consumptions of the variable air volume and unit ventilator systems were significantly below those of reheat and dual-duct systems. This reflects the nature of the former two systems which try to match the system capacities to the changing building loads. The heating energy savings of unit ventilators were especially large. In most cities the unit ventilators consumed less than one-fifth of the heating energy of the other systems. The variable air volume systems performed better than the unit

ventilators in cooling energy consumption. Comparison data may be seen in paragraph C of section 3.2.

E. Substantial air transportation energy savings were obtained when variable air volume and unit ventilator systems were used. Dual-duct systems used more energy for transporting air than the other systems compared in this study, because of the added pressure requirements of the mixing boxes. The numerical comparisons are shown in paragraph D of section 3.2.

F. The difference in operating hours of the air handling systems resulted in substantial difference in energy consumption. The cooling, heating, and fan energy consumption ratios (10 hours a day operation vs operation according to occupancy schedules) of the entire school, with the classrooms and offices under base reheat, were 28 to 35 percent, 12 to 48 percent, and 14 to 43 percent, respectively. Detailed ratios may be found in paragraph E of section 3.2.

It should be mentioned again that the energy consumption predictions presented in this study were based on assumptions for a particular school building using one set of construction, orientation, and internal loads. The energy consumption boundary of this study was at the energy inlets of the air handling systems. Therefore, plant efficiencies, energy transmission losses, and energy costs should also be considered in order to use the data given in this study for control strategy selections and for preliminary design purposes.

5. REFERENCE

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Table 1. Annual Energy Consumption - Lake Charles, LA

Case	Strategy	Cooling Energy Btu x 10^9	Heating Energy Btu x 10^9	Fan Energy Btu x 10^9
For Classrooms and Offices (C&O):				
1	Base RH	1.682	0.671	0.190
2.	Base RH + temperature economy	1.549	0.683	0.190
3	Base RH + enthalpy economy	1.422	0.694	0.190
4	Base RH + supply air reset by zone cooling demand	1.331	0.379	0.190
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	1.129	0.396	0.190
6	Base VA	1.023	0.080	0.117
7	Base VA + temperature economy	0.998	0.081	0.117
8	Base VA + enthalpy economy	0.960	0.082	0.117
9	Base VA + supply air reset by zone cooling demand	0.959	0.055	0.134
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	0.892	0.055	0.133
11	Base DD	1.490	0.496	0.212
12	Base DD + enthalpy economy	1.275	0.571	0.212
13	Base DD + enthalpy economy + hot air reset	0.979	0.299	0.212
14	Base DD + hot & cold air reset	1.068	0.113	0.211
15	UV	1.019	0.001	0.118
For Entire School				
16	C/O—Case 1, Non-C/O—base*	2.523	1.501	0.331
17	C/O—Case 1, Non-C/O—base	1.874	0.701	0.232
18	C/O—Case 3, Non-C/O—base + enthalpy economy	1.608	0.724	0.232
19	C/O—Case 5, Non-C/O—base + enthalpy economy	1.315	0.426	0.232
20	C/O—Case 6, Non-C/O—base	1.215	0.110	0.159
21	C/O—Case 8, Non-C/O—base + enthalpy economy	1.145	0.111	0.159
22	C/O—Case 5, Non-C/O—base + enthalpy economy	1.078	0.085	0.175
23	C/O—Case 11, Non-C/O—base	1.683	0.526	0.254
24	C/O—Case 13, Non-C/O—base + enthalpy economy	1.164	0.328	0.254
25	C/O—Case 14, Non-C/O—base + enthalpy economy	1.254	0.143	0.254
26	C/O—Case 15, Non-C/O—base + enthalpy economy	1.205	0.031	0.160

* Air handling systems operating 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

Table 2. Annual Energy Consumption - Madison, WI

Case	Strategy	Cooling Energy Btu x 10^9	Heating Energy Btu x 10^9	Fan Energy Btu x 10^9
For Classrooms and Offices (C&O):				
1	Base RH	0.982	1.711	0.392
2.	Base RH + temperature economy	0.663	1.739	0.392
3	Base RH + enthalpy economy	0.522	1.752	0.392
4	Base RH + supply air reset by zone cooling demand	0.620	1.373	0.392
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	0.343	1.397	0.392
6	Base VA	0.354	1.042	0.211
7	Base VA + temperature economy	0.329	1.043	0.211
8	Base VA + enthalpy economy	0.283	1.044	0.211
9	Base VA + supply air reset by zone cooling demand	0.312	1.057	0.220
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	0.235	1.057	0.219
11	Base DD	0.812	1.506	0.436
12	Base DD + enthalpy economy	0.451	1.660	0.436
13	Base DD + enthalpy economy + hot air reset	0.295	1.504	0.436
14	Base DD + hot & cold air reset	0.460	1.164	0.436
15	UV	0.344	0.329	0.170
For Entire School				
16	C/O—Case 1, AUS—base*	1.320	2.715	0.569
17	C/O—Case 1, Non-C/O—base	1.029	2.424	0.501
18	C/O—Case 3, Non-C/O—base + enthalpy economy	0.563	2.465	0.501
19	C/O—Case 5, Non-C/O—base + enthalpy economy	0.383	2.111	0.501
20	C/O—Case 6, Non-C/O—base	0.402	1.756	0.321
21	C/O—Case 8, Non-C/O—base + enthalpy economy	0.324	1.757	0.321
22	C/O—Case 5, Non-C/O—base + enthalpy economy	0.276	1.770	0.329
23	C/O—Case 11, Non-C/O—base	0.859	2.219	0.546
24	C/O—Case 13, Non-C/O—base + enthalpy economy	0.336	2.217	0.546
25	C/O—Case 14, Non-C/O—base + enthalpy economy	0.501	1.877	0.546
26	C/O—Case 15, Non-C/O—base + enthalpy economy	0.385	1.043	0.280

* Air handling systems operating 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

Table 3. Annual Energy Consumption - Nashville, TN

Case	Strategy	Cooling Energy Btu x 10^9	Heating Energy Btu x 10^9	Fan Energy Btu x 10^9
For Classrooms and Offices (C&O):				
1	Base RH	1.366	0.977	0.260
2.	Base RH + temperature economy	1.096	1.001	0.260
3	Base RH + enthalpy economy	0.937	1.015	0.260
4	Base RH + supply air reset by zone cooling demand	0.992	0.644	0.260
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	0.687	0.671	0.260
6	Base VA	0.683	0.319	0.149
7	Base VA + temperature economy	0.646	0.320	0.149
8	Base VA + enthalpy economy	0.601	0.321	0.149
9	Base VA + supply air reset by zone cooling demand	0.621	0.295	0.164
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	0.540	0.295	0.164
11	Base DD	1.178	0.787	0.287
12	Base DD + enthalpy economy	0.831	0.923	0.287
13	Base DD + enthalpy economy + hot air reset	0.622	0.727	0.287
14	Base DD + hot & cold air reset	0.775	0.418	0.287
15	UV	0.664	0.055	0.130
For Entire School				
16	C/O—Case 1, Non-C/O—base*	1.963	1.592	0.416
17	C/O—Case 1, Non-C/O—base	1.480	1.139	0.324
18	C/O—Case 3, Non-C/O—base + enthalpy economy	1.045	1.177	0.324
19	C/O—Case 5, Non-C/O—base + enthalpy economy	0.795	0.833	0.324
20	C/O—Case 6, Non-C/O—base	0.797	0.481	0.214
21	C/O—Case 8, Non-C/O—base + enthalpy economy	0.709	0.483	0.214
22	C/O—Case 5, Non-C/O—base + enthalpy economy	0.648	0.457	0.228
23	C/O—Case 11, Non-C/O—base	1.293	0.949	0.352
24	C/O—Case 13, Non-C/O—base + enthalpy economy	0.730	0.889	0.352
25	C/O—Case 14, Non-C/O—base + enthalpy economy	0.883	0.580	0.352
26	C/O—Case 15, Non-C/O—base + enthalpy economy	0.772	0.217	0.194

* Air handling systems operating 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

Table 4. Annual Energy Consumption - Santa Maria, CA

Case	Strategy	Cooling Energy Btu x 10^9	Heating Energy Btu x 10^9	Fan Energy Btu x 10^9
For Classrooms and Offices (C&O):				
1	Base RH	1.166	0.856	0.168
2.	Base RH + temperature economy	1.014	0.870	0.168
3	Base RH + enthalpy economy	0.541	0.912	0.168
4	Base RH + supply air reset by zone cooling demand	0.792	0.493	0.168
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	0.258	0.539	0.168
6	Base VA	0.422	0.146	0.090
7	Base VA + temperature economy	0.388	0.147	0.090
8	Base VA + enthalpy economy	0.235	0.151	0.090
9	Base VA + supply air reset by zone cooling demand	0.305	0.064	0.094
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	0.131	0.067	0.093
11	Base DD	0.964	0.644	0.189
12	Base DD + enthalpy economy	0.448	0.817	0.189
13	Base DD + enthalpy economy + hot air reset	0.230	0.591	0.189
14	Base DD + hot & cold air reset	0.514	0.188	0.189
15	UV	0.325	0.007	0.106
For Entire School				
16	C/O—Case 1, Non-C/O—base*	1.560	1.325	0.273
17	C/O—Case 1, Non-C/O—base	1.192	0.897	0.196
18	C/O—Case 3, Non-C/O—base + enthalpy economy	0.560	0.952	0.196
19	C/O—Case 5, Non-C/O—base + enthalpy economy	0.276	0.580	0.196
20	C/O—Case 6, Non-C/O—base	0.448	0.187	0.118
21	C/O—Case 8, Non-C/O—base + enthalpy economy	0.253	0.191	0.118
22	C/O—Case 5, Non-C/O—base + enthalpy economy	0.149	0.107	0.121
23	C/O—Case 11, Non-C/O—base	0.990	0.684	0.217
24	C/O—Case 13, Non-C/O—base + enthalpy economy	0.248	0.631	0.217
25	C/O—Case 14, Non-C/O—base + enthalpy economy	0.533	0.228	0.217
26	C/O—Case 15, Non-C/O—base + enthalpy economy	0.343	0.047	0.135

* Air handling systems operating 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

Table 5. Annual Energy Consumption - Seattle, WA

Case	Strategy	Cooling Energy Btu x 10^9	Heating Energy Btu x 10^9	Fan Energy Btu x 10^9
For Classrooms and Offices (C&O):				
1	Base RH	0.963	1.191	0.291
2.	Base RH + temperature economy	0.497	1.220	0.291
3	Base RH + enthalpy economy	0.241	1.232	0.291
4	Base RH + supply air reset by zone cooling demand	0.603	0.846	0.291
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	.0.116	0.873	0.291
6	Base VA	0.266	0.529	0.160
7	Base VA + temperature economy	0.192	0.531	0.160
8	Base VA + enthalpy economy	0.109	0.531	0.160
9	Base VA + supply air reset by zone cooling demand	0.185	0.513	0.164
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	0.067	0.514	0.164
11	Base DD	0.785	0.995	0.316
12	Base DD + enthalpy economy	0.206	1.144	0.316
13	Base DD + enthalpy economy + hot air reset	0.124	1.504	0.316
14	Base DD + hot & cold air reset	0.434	0.571	0.316
15	UV	0.175	0.059	0.127
For Entire School				
16	C/O—Case 1, Non-C/O—base*	1.264	1.662	0.419
17	C/O—Case 1, Non-C/O—base	0.980	1.290	0.319
18	C/O—Case 3, Non-C/O—base + enthalpy economy	0.252	1.354	0.319
19	C/O—Case 5, Non-C/O—base + enthalpy economy	0.127	0.981	0.319
20	C/O—Case 6, Non-C/O—base	0.277	0.539	0.188
21	C/O—Case 8, Non-C/O—base + enthalpy economy	0.120	0.543	0.188
22	C/O—Case 5, Non-C/O—base + enthalpy economy	0.077	0.501	0.192
23	C/O—Case 11, Non-C/O—base	0.802	1.084	0.344
24	C/O—Case 13, Non-C/O—base + enthalpy economy	0.134	1.205	0.344
25	C/O—Case 14, Non-C/O—base + enthalpy economy	0.445	0.722	0.344
26	C/O—Case 15, Non-C/O—base + enthalpy economy	0.186	0.209	0.155

* Air handling systems operating 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

Table 6. Annual Energy Consumption - Washington, D.C.

Case	Strategy	Cooling Energy Btu x 10^9	Heating Energy Btu x 10^9	Fan Energy Btu x 10^9
For Classrooms and Offices (C&O):				
1	Base RH	1.221	1.191	0.319
2.	Base RH + temperature economy	0.893	1.220	0.319
3	Base RH + enthalpy economy	0.749	1.232	0.319
4	Base RH + supply air reset by zone cooling demand	0.842	0.846	0.319
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	0.529	0.873	0.319
6	Base VA	0.544	0.529	0.178
7	Base VA + temperature economy	0.500	0.531	0.178
8	Base VA + enthalpy economy	0.456	0.531	0.178
9	Base VA + supply air reset by zone cooling demand	0.486	0.513	0.191
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	0.404	0.514	0.190
11	Base DD	1.039	0.995	0.352
12	Base DD + enthalpy economy	0.658	1.144	0.352
13	Base DD + enthalpy economy + hot air reset	0.470	0.965	0.352
14	Base DD + hot & cold air reset	0.649	0.630	0.352
15	UV	0.515	0.123	0.142
For Entire School				
16	C/O—Case 1, Non-C/O—base*	1.712	1.902	0.490
17	C/O—Case 1, Non-C/O—base	1.306	1.496	0.405
18	C/O—Case 3, Non-C/O—base + enthalpy economy	0.827	1.538	0.405
19	C/O—Case 5, Non-C/O—base + enthalpy economy	0.607	1.179	0.405
20	C/O—Case 6, Non-C/O—base	0.622	0.835	0.263
21	C/O—Case 8, Non-C/O—base + enthalpy economy	0.534	0.837	0.263
22	C/O—Case 5, Non-C/O—base + enthalpy economy	0.483	0.819	0.276
23	C/O—Case 11, Non-C/O—base	1.123	1.301	0.438
24	C/O—Case 13, Non-C/O—base + enthalpy economy	0.548	1.270	0.438
25	C/O—Case 14, Non-C/O—base + enthalpy economy	0.727	0.935	0.438
26	C/O—Case 15, Non-C/O—base + enthalpy economy	0.593	0.428	0.228

* Air handling systems operating 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat
VA = variable air volume
DD = dual-duct
UV = unit ventilator

Table 7. Comparative Annual Energy Consumption - Lake Charles, LA

Case	Strategy	Cooling Energy	Heating Energy	Fan Energy
		Consumption, 10^3 Btu/ft^2		
		Ratio-Relative to Case 1		
For Classroom and Offices (C&O):				
1	Base RH	37.99 1.00	15.16 1.00	4.28 1.00
2	Base RH + temperature economy	34.99 0.92	15.43 1.02	4.28 1.00
3	Base RH + enthalpy economy	32.12 0.85	15.68 1.03	4.28 1.00
4	Base RH + supply air reset by zone cooling demand	30.07 0.79	8.56 0.56	4.28 1.00
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	25.50 0.67	8.95 0.59	4.28 1.00
6	Base VA	23.11 0.61	1.80 0.12	2.63 0.62
7	Base VA + temperature economy	22.54 0.59	1.82 0.12	2.63 0.62
8	Base VA + enthalpy economy	21.69 0.57	1.84 0.12	2.63 0.62
9	Base VA + supply air reset by zone cooling demand	21.66 0.57	1.24 0.08	3.02 0.70
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	20.15 0.53	1.24 0.08	3.00 0.70
11	Base DD	33.66 0.89	11.20 0.74	4.79 1.12
12	Base DD + enthalpy economy	28.80 0.76	12.90 0.85	4.79 1.12
13	Base DD + enthalpy economy + hot air reset	22.11 0.58	6.75 0.45	4.79 1.12
14	Base DD + hot & cold air reset	24.13 0.63	2.55 0.17	4.79 1.12
15	UV	23.02 0.61	0.03 0.002	2.67 0.62
For Entire School				
16	CO—Case 1, Non-C/O—base*	42.56 1.35	25.32 2.14	5.58 1.43
17	CO—Case 1, Non-C/O—base	31.61 1.00	11.82 1.00	3.91 1.00
18	CO—Case 3, Non-C/O—base + enthalpy economy	27.12 0.86	12.21 1.03	3.91 1.00
19	C/O—Case 5, Non-C/O—base + enthalpy economy	22.18 0.70	7.19 0.61	3.91 1.00
20	C/O—Case 6, Non-C/O—base	20.49 0.65	1.86 0.16	2.68 0.69
21	C/O—Case 8, Non-C/O—base + enthalpy economy	19.31 0.61	1.87 0.16	2.68 0.69
22	C/O—Case 5, Non-C/O—base + enthalpy economy	18.18 0.58	1.43 0.12	2.95 0.75
23	C/O—Case 11, Non-C/O—base	28.39 0.90	8.87 0.75	4.28 1.09
24	C/O—Case 13, Non-C/O—base + enthalpy economy	19.63 0.62	5.53 0.47	4.28 1.09
25	C/O—Case 14, Non-C/O—base + enthalpy economy	21.15 0.67	2.41 0.20	4.28 1.09
26	C/O—Case 15, Non-C/O—base + enthalpy economy	20.33 0.64	0.52 0.04	2.70 0.69

* Air handling systems on 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas--auditorium, cafeteria, kitchen, and gymnasium
RH = reheat DD = dual-duct
VA = variable air volume UV = unit ventilator

Table 8. Comparative Annual Energy Consumption - Madison, WI

Case	Strategy	Cooling Energy	Heating Energy	Fan Energy
		Consumption, 10^3 Btu/ft^2		
		Ratio-Relative to Case 1		
For Classroom and Offices (C&O):				
1	Base RH	22.18 1.00	38.65 1.00	8.85 1.00
2	Base RH + temperature economy	14.98 0.68	39.28 1.02	8.85 1.00
3	Base RH + enthalpy economy	11.79 0.53	39.58 1.02	8.85 1.00
4	Base RH + supply air reset by zone cooling demand	14.01 0.63	31.01 0.80	8.85 1.00
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	7.75 0.35	31.56 0.82	8.85 1.00
6	Base VA	7.80 0.36	23.54 0.82	4.77 0.54
7	Base VA + temperature economy	7.80 0.36	23.54 0.61	4.77 0.54
8	Base VA + enthalpy economy	7.43 0.33	23.56 0.61	4.77 0.54
9	Base VA + supply air reset by zone cooling demand	6.39 0.29	23.58 0.62	4.97 0.56
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	5.31 0.24	23.88 0.62	4.95 0.56
11	Base DD	18.34 0.83	34.02 0.88	9.85 1.11
12	Base DD + enthalpy economy	10.19 0.46	37.50 0.97	9.85 1.11
13	Base DD + enthalpy economy + hot air reset	6.66 0.30	33.97 0.88	9.85 1.11
14	Base DD + hot & cold air reset	10.39 0.47	26.29 0.68	9.85 1.11
15	UV	7.77 0.35	7.43 0.19	3.84 0.43
For Entire School				
16	C/O—case 1, Non-C/O—base*	22.27 1.28	45.80 1.12	9.60 1.14
17	C/O—case 1, Non-C/O—base	17.36 1.00	40.89 1.00	8.45 1.00
18	C/O—case 3, Non-C/O—base + enthalpy economy	9.50 0.55	41.58 1.02	8.45 1.00
19	C/O—Case 5, Non-C/O—base + enthalpy economy	6.46 0.37	35.61 0.87	8.45 1.00
20	C/O—Case 6, Non-C/O—base	6.78 0.39	29.62 0.72	5.41 0.64
21	C/O—Case 8, Non-C/O—base + enthalpy economy	5.47 0.31	29.64 0.72	5.41 0.64
22	C/O—Case 5, Non-C/O—base + enthalpy economy	4.66 0.27	29.86 0.73	5.55 0.66
23	C/O—Case 11, Non-C/O—base	14.49 0.83	37.43 0.92	9.21 1.09
24	C/O—Case 13, Non-C/O—base + enthalpy economy	5.67 0.33	37.40 0.91	9.21 1.09
25	C/O—Case 14, Non-C/O—base + enthalpy economy	8.45 0.49	31.66 0.77	9.21 1.09
26	C/O—Case 15, Non-C/O—base + enthalpy economy	6.49 0.37	17.59 0.43	4.72 0.56

* Air handling systems on 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas--auditorium, cafeteria, kitchen, and gymnasium
RH = reheat DD = dual-duct
VA = variable air volume UV = unit ventilator

Table 9. Comparative Annual Energy Consumption - Nashville, TN

Case	Strategy	Cooling Energy	Heating Energy	Fan Energy
		Consumption, 10^3 Btu/ft^2		
		Ratio-Relative to Case 1		
For Classroom and Offices (C&O):				
1	Base RH	30.86 1.00	22.07 1.00	5.87 1.00
2	Base RH + temperature economy	24.76 0.80	22.61 1.02	5.87 1.00
3	Base RH + enthalpy economy	21.17 0.69	22.93 1.04	5.87 1.00
4	Base RH + supply air reset by zone cooling demand	22.41 0.73	14.55 0.66	5.87 1.00
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	15.52 0.50	15.16 0.69	5.87 1.00
6	Base VA	15.43 0.50	7.21 0.33	3.37 0.57
7	Base VA + temperature economy	14.59 0.47	7.23 0.33	3.37 0.57
8	Base VA + enthalpy economy	13.58 0.44	7.25 0.33	3.37 0.57
9	Base VA + supply air reset by zone cooling demand	14.03 0.45	6.66 0.30	3.70 0.63
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	12.20 0.40	6.66 0.30	3.70 0.63
11	Base DD	26.61 0.86	17.78 0.81	6.48 1.10
12	Base DD + enthalpy economy	18.77 0.61	20.85 0.94	6.48 1.10
13	Base DD + enthalpy economy + hot air reset	14.05 0.46	16.42 0.74	6.48 1.10
14	Base DD + hot & cold air reset	17.51 0.57	9.44 0.43	6.48 1.10
15	UV	15.00 0.49	1.24 0.06	2.94 0.50
For Entire School				
16	C/O—Case 1, Non-C/O—base*	33.11 1.33	26.85 1.40	7.02 1.28
17	C/O—Case 1, Non-C/O—base	24.96 1.00	19.21 1.00	5.47 1.00
18	C/O—Case 3, Non-C/O—base + enthalpy economy	17.63 0.71	19.85 1.03	5.47 1.00
19	C/O—Case 5, Non-C/O—base + enthalpy economy	13.41 0.54	14.05 0.73	5.47 1.00
20	C/O—Case 6, Non-C/O—base	13.44 0.54	8.11 0.42	3.61 0.66
21	C/O—Case 8, Non-C/O—base + enthalpy economy	11.96 0.48	8.15 0.42	3.61 0.66
22	C/O—Case 5, Non-C/O—base + enthalpy economy	10.93 0.44	7.71 0.57	3.85 0.70
23	C/O—Case 11, Non-C/O—base	21.81 0.87	16.01 0.83	5.94 1.09
24	C/O—Case 13, Non-C/O—base + enthalpy economy	12.31 0.49	15.00 0.78	5.94 1.09
25	C/O—Case 14, Non-C/O—base + enthalpy economy	14.89 0.60	9.78 0.51	5.94 1.09
26	C/O—Case 15, Non-C/O—base + enthalpy economy	13.02 0.52	3.66 0.19	3.27 0.60

* Air handling systems on 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas--auditorium, cafeteria, kitchen, and gymnasium
RH = reheat DD = dual-duct
VA = variable air volume UV = unit ventilator

Table 10. Comparative Annual Energy Consumption - Santa Maria, CA

Case	Strategy	Cooling Energy	Heating Energy	Fan Energy
		Consumption, 10^3 Btu/ft^2 Ratio-Relative to Case 1		
For Classroom and Offices (C&O):				
1	Base RH	26.34 1.00	19.34 1.00	3.79 1.00
2	Base RH + temperature economy	22.91 0.87	19.65 1.02	3.79 1.00
3	Base RH + enthalpy economy	12.22 0.46	20.60 1.07	3.79 1.00
4	Base RH + supply air reset by zone cooling demand	17.89 0.68	11.14 0.58	3.79 1.00
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	5.83 0.22	12.18 0.63	3.79 1.00
6	Base VA	9.53 0.36	3.30 0.17	2.03 0.54
7	Base VA + temperature economy	8.76 0.33	3.32 0.17	2.03 0.54
8	Base VA + enthalpy economy	5.31 0.20	3.41 0.18	2.03 0.54
9	Base VA + supply air reset by zone cooling demand	6.89 0.26	1.45 0.07	2.12 0.56
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	2.96 0.11	1.51 0.08	2.10 0.55
11	Base DD	21.78 0.83	14.55 0.75	4.27 1.13
12	Base DD + enthalpy economy	10.12 0.38	18.46 0.95	4.27 1.13
13	Base DD + enthalpy economy + hot air reset	5.20 0.20	13.35 0.69	4.27 1.13
14	Base DD + hot & cold air reset	11.61 0.44	4.25 0.22	4.27 1.13
15	UV	7.34 0.28	0.16 0.01	2.39 0.63
For Entire School				
16	C/O—Case 1, Non-C/O—base*	26.31 1.31	22.35 1.48	4.60 1.39
17	C/O—Case 1, Non-C/O—base	20.11 1.00	15.13 1.00	3.31 1.00
18	C/O—Case 3, Non-C/O—base + enthalpy economy	9.45 0.47	16.06 1.06	3.31 1.00
19	C/O--Case 5, Non-C/O—base + enthalpy economy	4.66 0.23	9.78 0.65	3.31 1.00
20	C/O—Case 6, Non-C/O—base	7.56 0.38	3.15 0.21	1.99 0.60
21	C/O—Case 8, Non-C/O—base + enthalpy economy	4.27 0.21	3.22 0.21	1.99 0.60
22	C/O—Case 5, Non-C/O—base + enthalpy economy	2.51 0.13	1.80 0.12	2.04 0.62
23	C/O—Case 11, Non-C/O—base	16.70 0.83	11.54 0.76	3.66 1.11
24	C/O—Case 13, Non-C/O—base + enthalpy economy	4.18 0.21	10.64 0.70	3.66 1.11
25	C/O—Case 14, Non-C/O—base + enthalpy economy	8.99 0.45	3.85 0.25	3.66 1.11
26	C/O--Case 15, Non-C/O—base + enthalpy economy	5.79 0.29	0.79 0.05	2.78 0.69

* Air handling systems on 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas--auditorium, cafeteria, kitchen, and gymnasium
RH = reheat DD = dual-duct
VA = variable air volume UV = unit ventilator

Table 11. Comparative Annual Energy Consumption - Seattle, WA

Case	Strategy	Cooling Energy	Heating Energy	Fan Energy
		Consumption, 10^3 Btu/ft^2 Ratio-Relative to Case 1		
For Classroom and Offices (C&O):				
1	Base RH	21.75 1.00	26.90 1.00	6.57 1.00
2	Base RH + temperature economy	11.23 0.52	27.56 1.02	6.57 1.00
3	Base RH + enthalpy economy	5.44 0.25	27.83 1.03	6.57 1.00
4	Base RH + supply air reset by zone cooling demand	13.62 0.63	19.11 0.71	6.57 1.00
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	2.62 0.12	19.72 0.73	6.57 1.00
6	Base VA	6.01 0.28	11.95 0.44	3.61 0.55
7	Base VA + temperature economy	4.37 0.20	11.99 0.45	3.61 0.55
8	Base VA + enthalpy economy	2.46 0.11	11.99 0.45	3.61 0.55
9	Base VA + supply air reset by zone cooling demand	4.18 0.19	11.59 0.43	3.70 0.56
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	1.51 0.07	11.61 0.43	3.70 0.56
11	Base DD	17.73 0.82	22.48 0.84	7.14 1.09
12	Base DD + enthalpy economy	4.65 0.21	25.84 0.96	7.14 1.09
13	Base DD + enthalpy economy + hot air reset	2.80 0.13	23.81 0.88	7.14 1.09
14	Base DD + hot & cold air reset	9.80 0.45	12.90 0.48	7.14 1.09
15	UV	3.95 0.18	1.33 0.05	2.87 0.44
For Entire School				
16	C/O—Case 1, Non-C/O—base*	21.32 1.29	28.03 1.29	7.07 1.31
17	C/O—Case 1, Non-C/O—base	16.53 1.00	21.76 1.00	5.38 1.00
18	C/O—Case 3, Non-C/O—base + enthalpy economy	4.25 0.26	22.84 1.05	5.38 1.00
19	C/O—Case 5, Non-C/O—base + enthalpy economy	2.14 0.13	16.55 0.76	5.38 1.00
20	C/O—Case 6, Non-C/O--base	4.67 0.28	9.09 0.42	3.17 0.59
21	C/O—Case 8, Non-C/O—base + enthalpy economy	2.02 0.12	9.16 0.42	3.17 0.59
22	C/O—Case 5, Non-C/O—base + enthalpy economy	1.30 0.08	8.45 0.39	3.24 0.60
23	C/O—Case 11, Non-C/O—base	13.53 0.82	18.28 0.84	5.80 1.08
24	C/O—Case 13, Non-C/O—base + enthalpy economy	2.26 0.14	20.33 0.93	5.80 1.08
25	C/O--Case 14, Non-C/O—base + enthalpy economy	7.51 0.45	12.18 0.59	5.80 1.08
26	C/O—Case 15, Non-C/O—base + enthalpy economy	3.14 0.19	3.53 0.16	2.61 0.49

* Air handling systems on 10 hours a day.

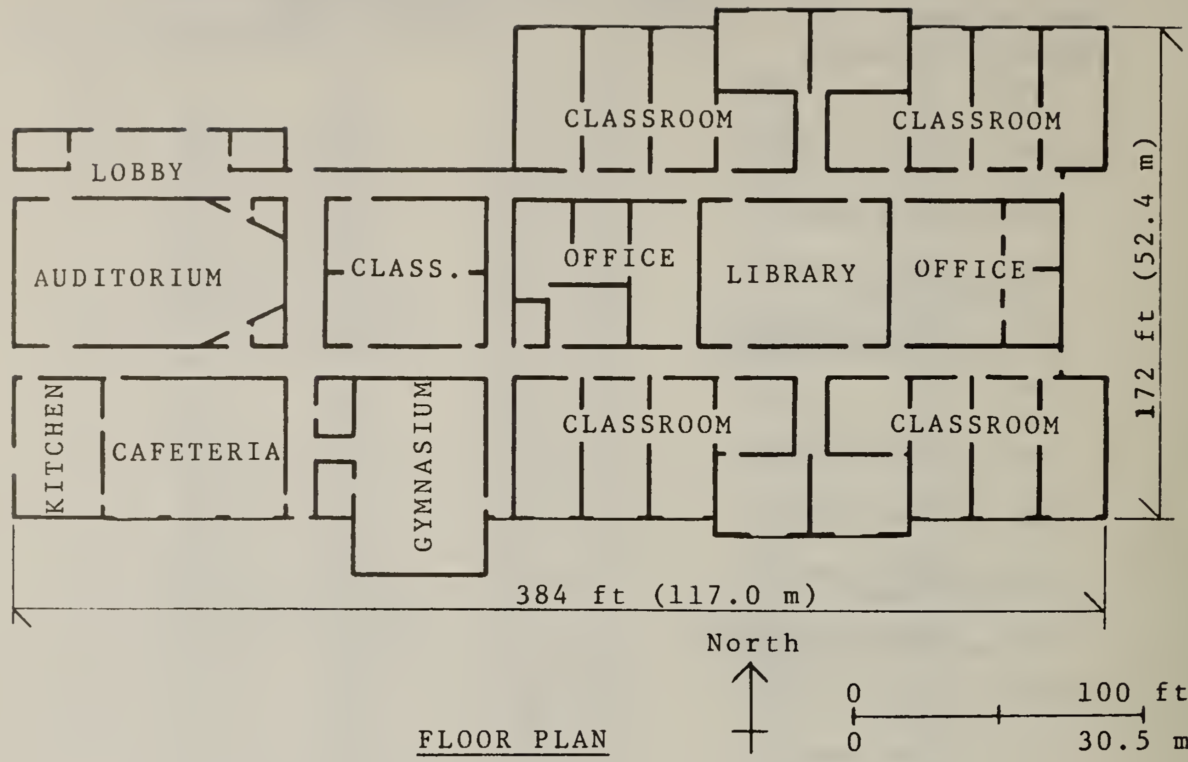
C/O = classroom/office areas
Non-C/O = Non-classroom/office areas--auditorium, cafeteria, kitchen, and gymnasium
RH = reheat DD = dual-duct
VA = variable air volume UV = unit ventilator

Table 12. Comparative Annual Energy Consumption - Washington, DC

Case	Strategy	Cooling Energy	Heating Energy	Fan Energy
		Consumption, 10^3 Btu/ft^2		
		Ratio-Relative to Case 1		
For Classroom and Offices (C&O):				
1	Base RH	27.58 1.00	26.90 1.00	7.21 1.00
2	Base RH + temperature economy	20.17 0.73	27.56 1.02	7.21 1.00
3	Base RH + enthalpy economy	16.92 0.61	27.83 1.03	7.21 1.00
4	Base RH + supply air reset by zone cooling demand	19.02 0.69	19.11 0.71	7.21 1.00
5	Base RH + enthalpy economy + supply air reset by zone cooling demand	11.95 0.43	19.72 0.73	7.21 1.00
6	Base VA	12.29 0.45	11.95 0.44	4.02 0.56
7	Base VA + temperature economy	11.29 0.41	11.99 0.45	4.02 0.56
8	Base VA + enthalpy economy	10.30 0.37	11.99 0.45	4.02 0.56
9	Base VA + supply air reset by zone cooling demand	10.98 0.40	11.59 0.43	4.31 0.60
10	Base VA + enthalpy economy + supply air reset by zone cooling demand	44.27 0.33	11.61 0.43	4.29 0.60
11	Base DD	23.47 0.85	22.48 0.83	7.95 1.10
12	Base DD + enthalpy economy	14.86 0.54	25.84 0.96	7.95 1.10
13	Base DD + enthalpy economy + hot air reset	10.62 0.38	21.80 0.81	7.95 1.10
14	Base DD + hot & cold air reset	14.66 0.53	14.23 0.53	7.95 1.10
15	UV	11.63 0.42	2.78 0.10	3.21 0.45
For Entire School				
16	CO—Case 1, Non-C/O—base*	28.88 1.31	32.08 1.27	8.27 1.21
17	CO—Case 1, Non-C/O—base	22.03 1.00	25.23 1.00	6.83 1.00
18	CO—Case 3, Non-C/O—base + enthalpy economy	13.95 0.63	25.94 1.03	6.83 1.00
19	C/O—Case 5, Non-C/O—base + enthalpy economy	10.24 0.46	19.89 0.79	6.83 1.00
20	C/O—Case 6, Non-C/O—base	10.49 0.48	14.08 0.56	4.44 0.65
21	C/O—Case 8, Non-C/O—base + enthalpy economy	9.01 0.41	14.12 0.56	4.44 0.65
22	C/O—Case 5, Non-C/O—base + enthalpy economy	8.15 0.37	13.81 0.55	4.66 0.68
23	C/O—Case 11, Non-C/O—base	18.94 0.86	21.95 0.87	7.39 1.08
24	C/O—Case 13, Non-C/O—base + enthalpy economy	9.24 0.42	21.42 0.85	7.39 1.08
25	C/O—Case 14, Non-C/O—base + enthalpy economy	12.26 0.56	15.77 0.63	7.39 1.08
26	C/O—Case 15, Non-C/O—base + enthalpy economy	10.00 0.45	7.22 0.29	3.85 0.56

* Air handling systems on 10 hours a day.

C/O = classroom/office areas
Non-C/O = Non-classroom/office areas—auditorium, cafeteria, kitchen, and gymnasium
RH = reheat DD = dual-duct
VA = variable air volume UV = unit ventilator



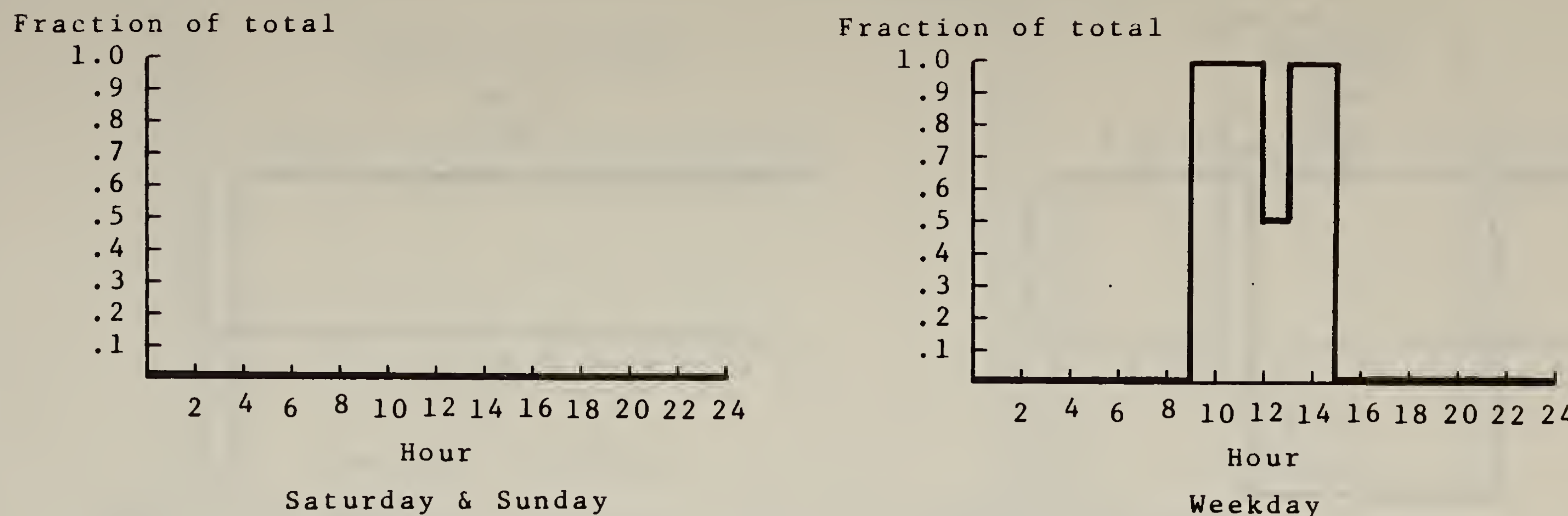
Exterior Wall:
4" (102 mm) face brick, 2" (51 mm) rigid insulation, and
8" (203 mm) concrete block

Roof:
built-up roof, 2" (51 mm) rigid insulation, metal deck,
air space, and 3/4" (19 mm) ceiling panels

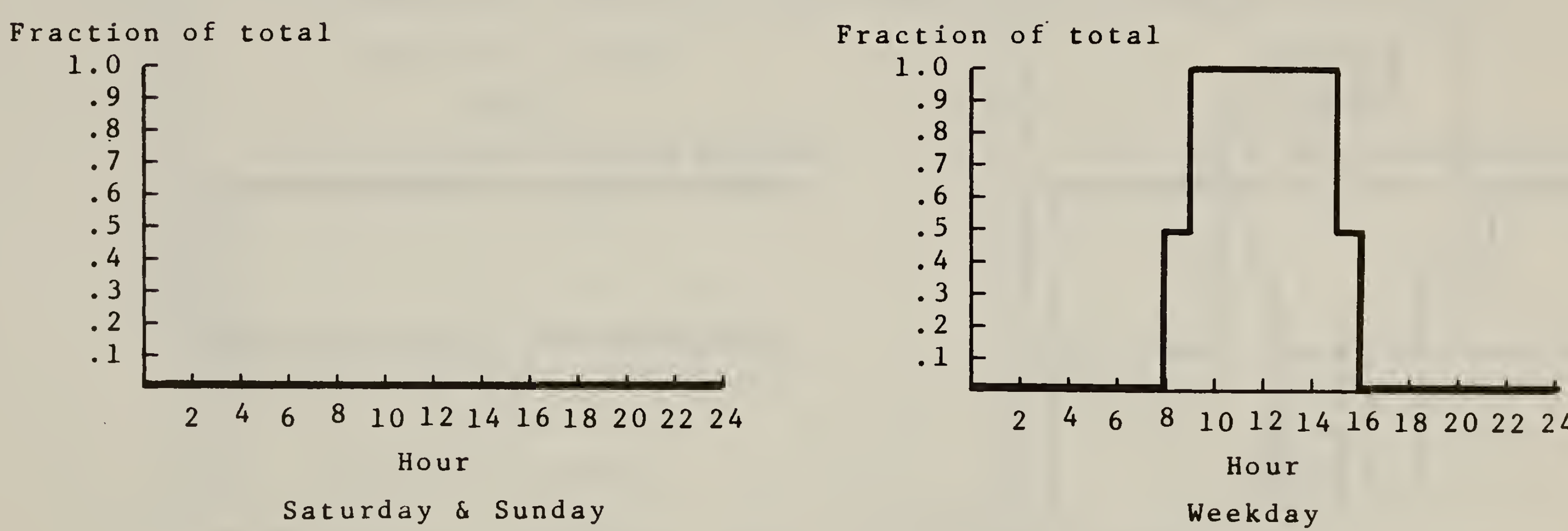
Partition:
8" (203 mm) concrete block, or
1/2" (13 mm) gypsum board on both sides of metal frame

Window:
single pane sheet glass and light color ventilation blind

Figure 1. School building model

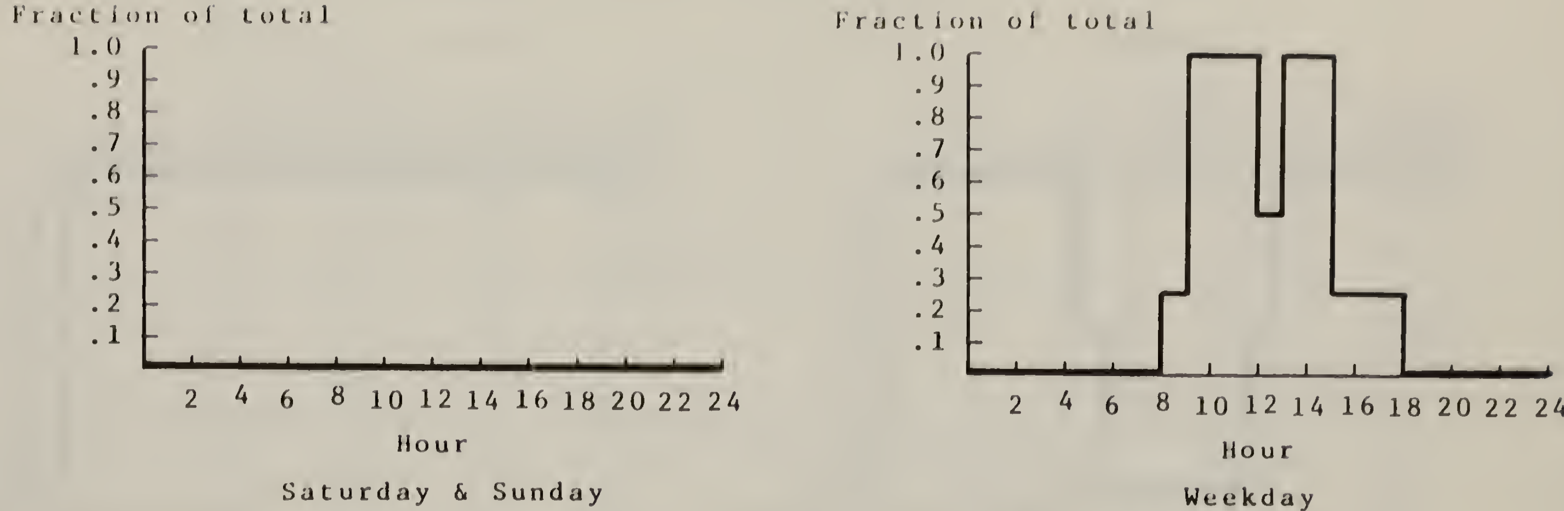


OCCUPANCY SCHEDULES peak load: 25 ft^2 ($2.32 m^2$) per person

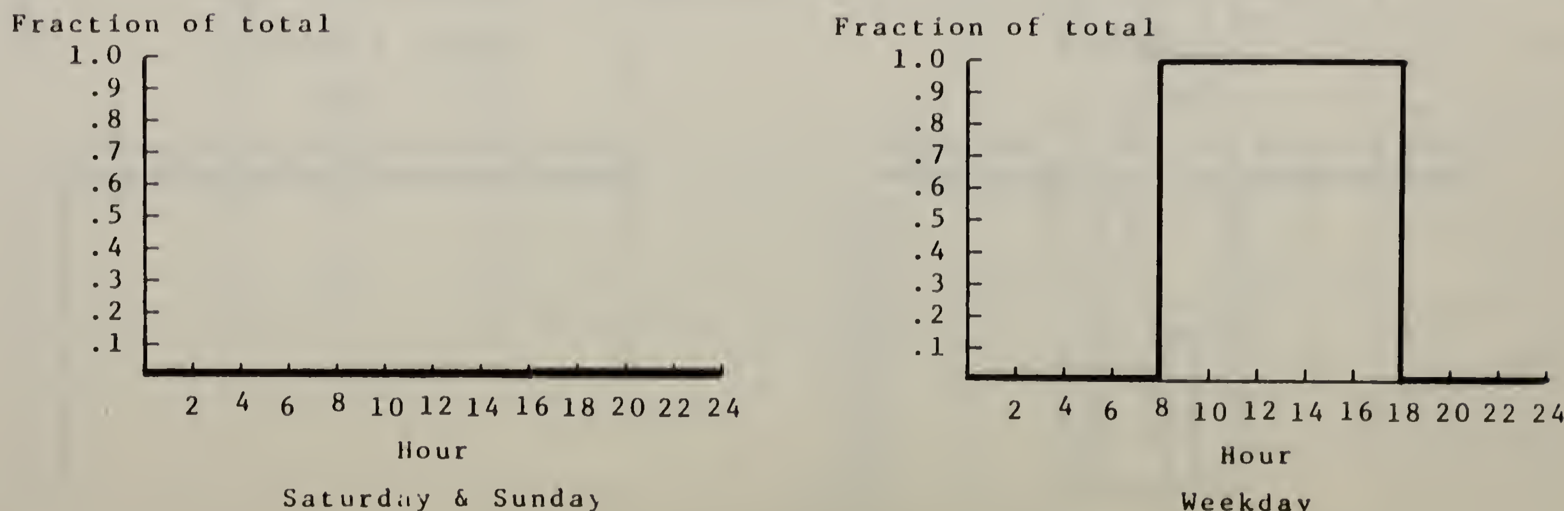


LIGHTING SCHEDULES peak load: 2.5 W/ft^2 (26.9 W/m^2)

Figure 2. Classroom internal load profiles

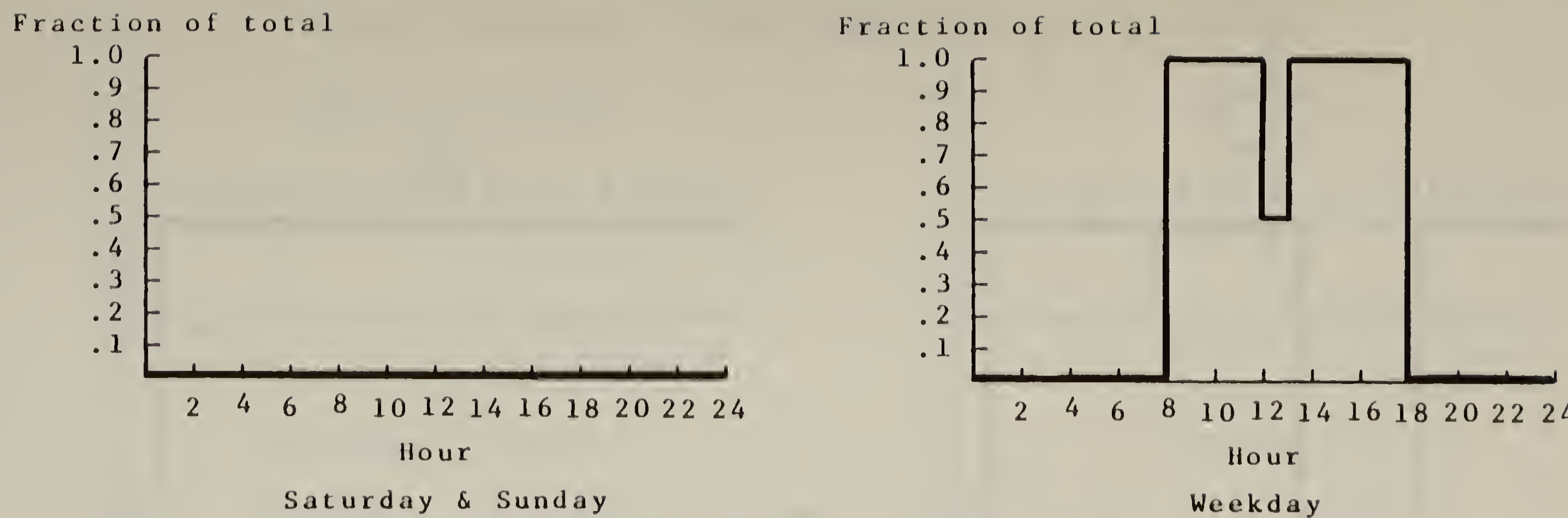


OCCUPANCY SCHEDULES peak load: 50 ft^2 (4.65 m^2) per person

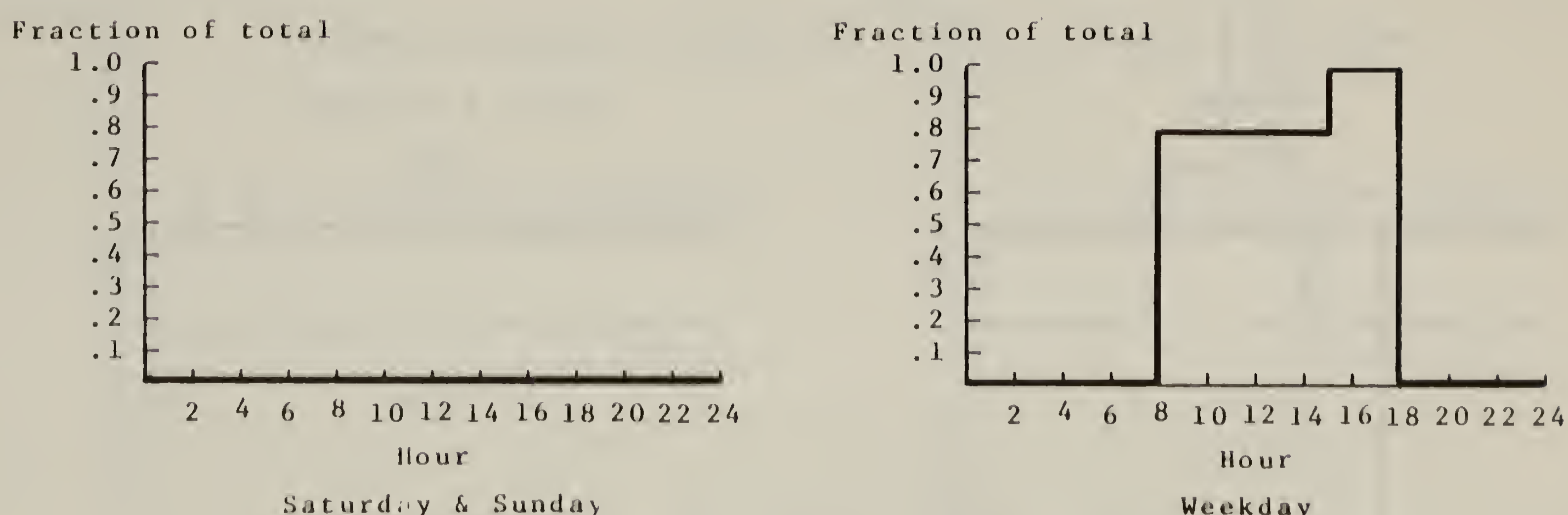


LIGHTING SCHEDULES peak load: 2.5 W/ft^2 (26.9 W/m^2)

Figure 3. Library internal load profiles

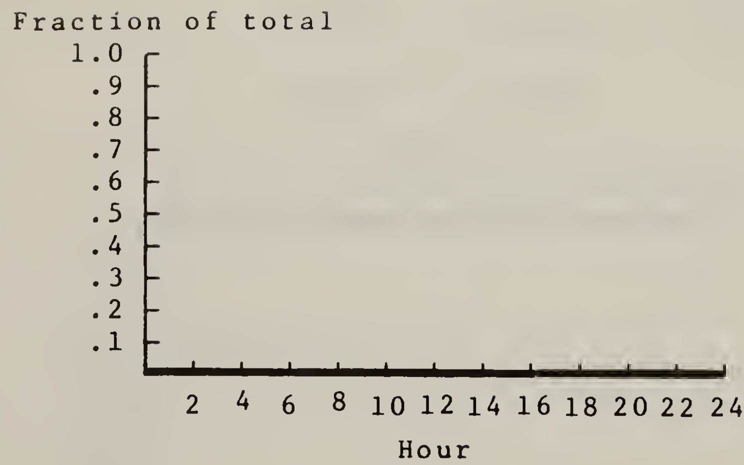


OCCUPANCY SCHEDULES peak load: 100 ft^2 (9.3 m^2) per person

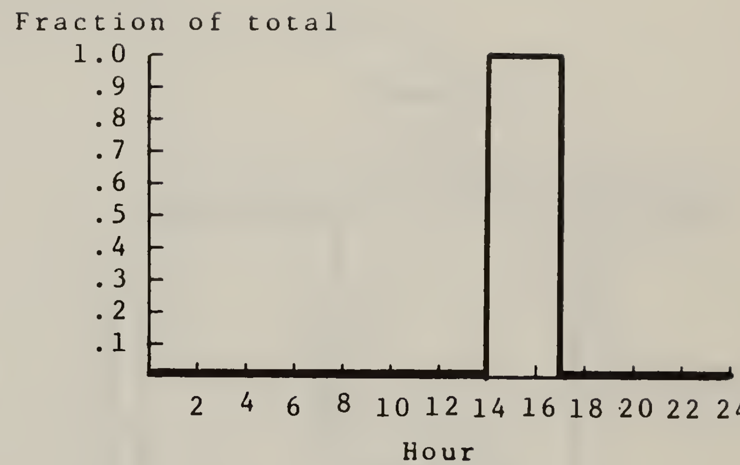


LIGHTING SCHEDULES peak load: 3.0 W/ft^2 (32.3 W/m^2)

Figure 4. Office internal load profiles

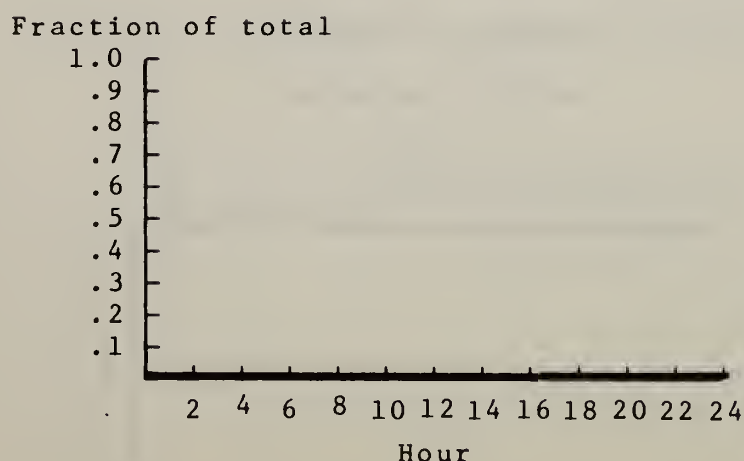


Saturday & Sunday

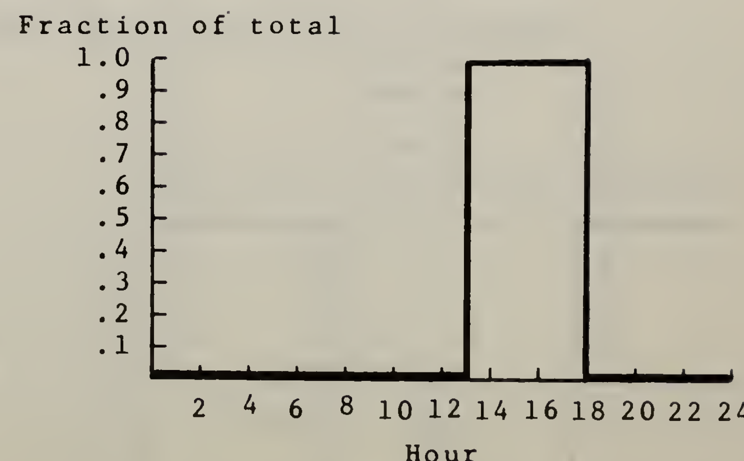


Weekday

OCCUPANCY SCHEDULES peak load: 12 ft^2 ($1.11 m^2$) per person



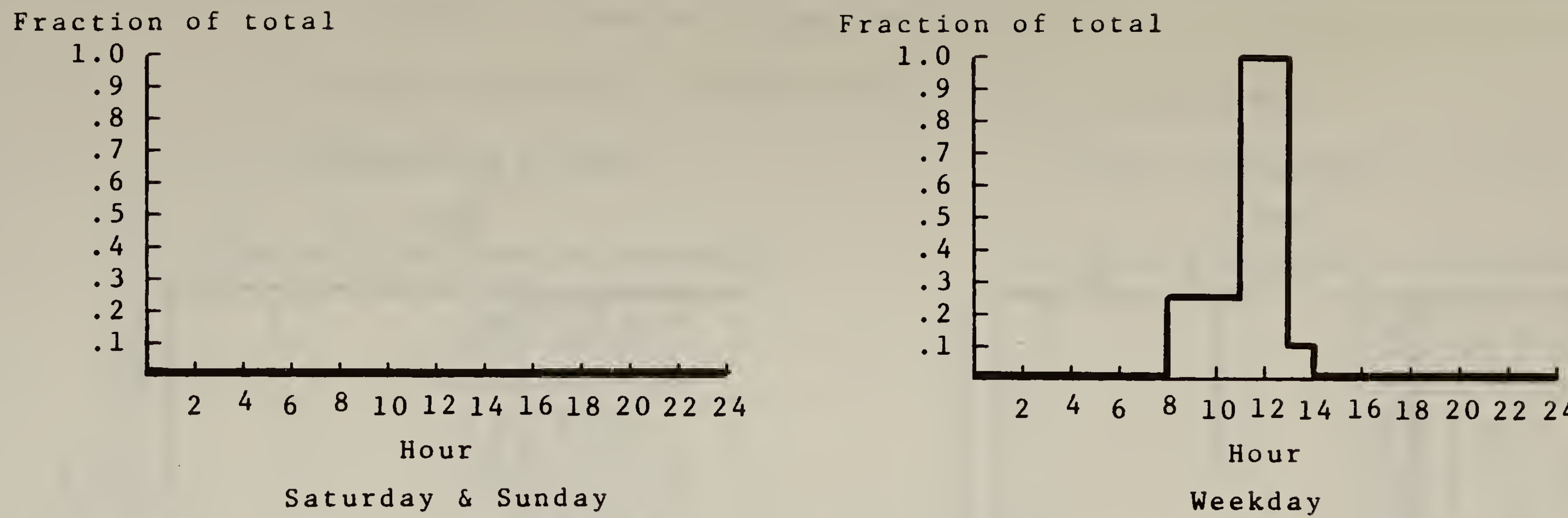
Saturday & Sunday



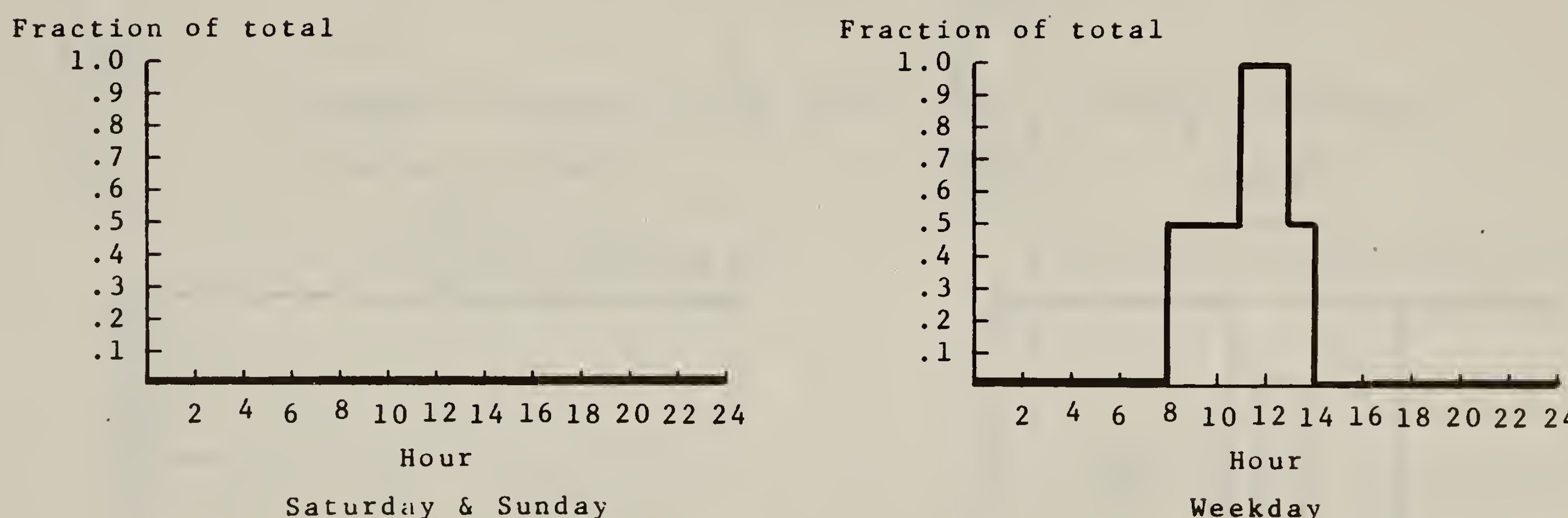
Weekday

LIGHTING SCHEDULES peak load: 0.8 W/ft^2 (8.6 W/m^2)

Figure 5. Auditorium internal load profiles

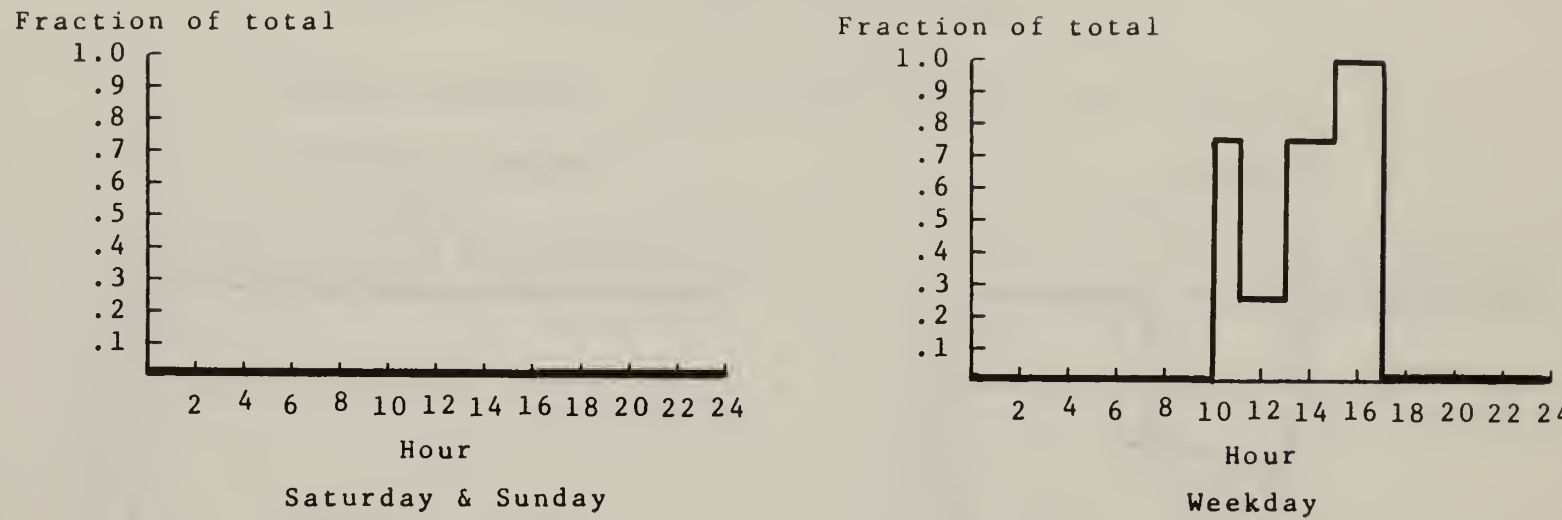


OCCUPANCY SCHEDULES peak load: 10 ft^2 ($0.93 m^2$) per person

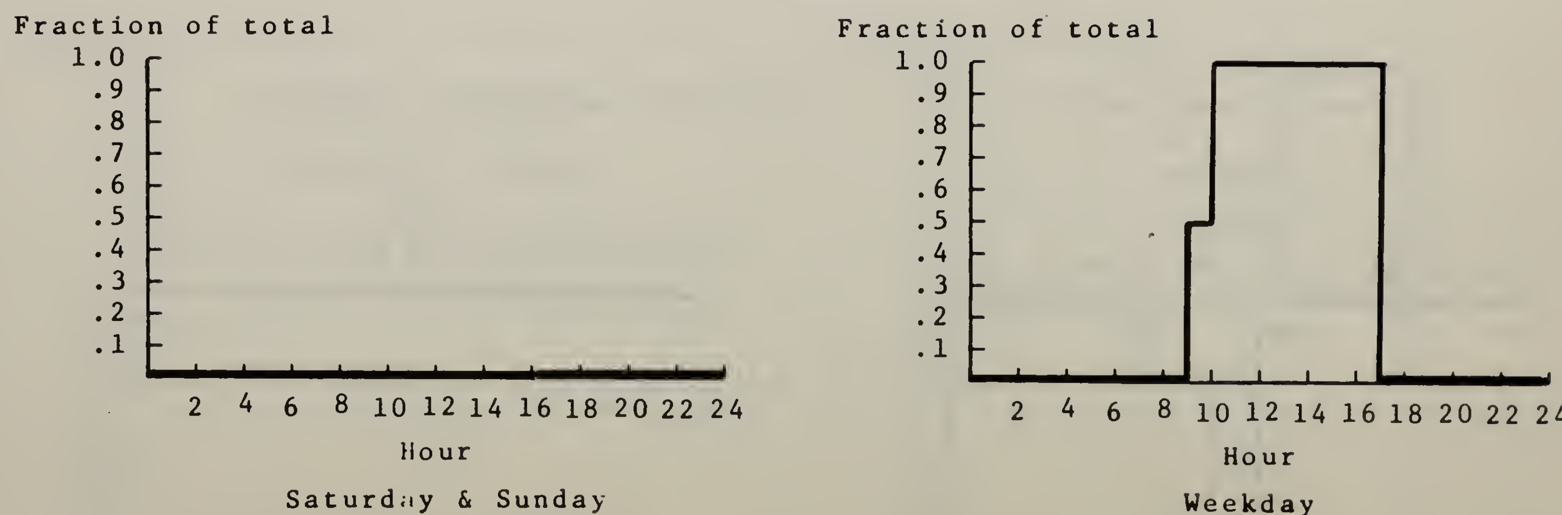


LIGHTING SCHEDULES peak load: 1.5 W/ft^2 (16.1 W/m^2)

Figure 6. Cafeteria internal load profiles



OCCUPANCY SCHEDULES peak load: 16 ft^2 ($1.49 m^2$) per person



LIGHTING SCHEDULES peak load: 0.8 W/ft^2 (8.6 W/m^2)

Figure 7. Gymnasium internal load profiles

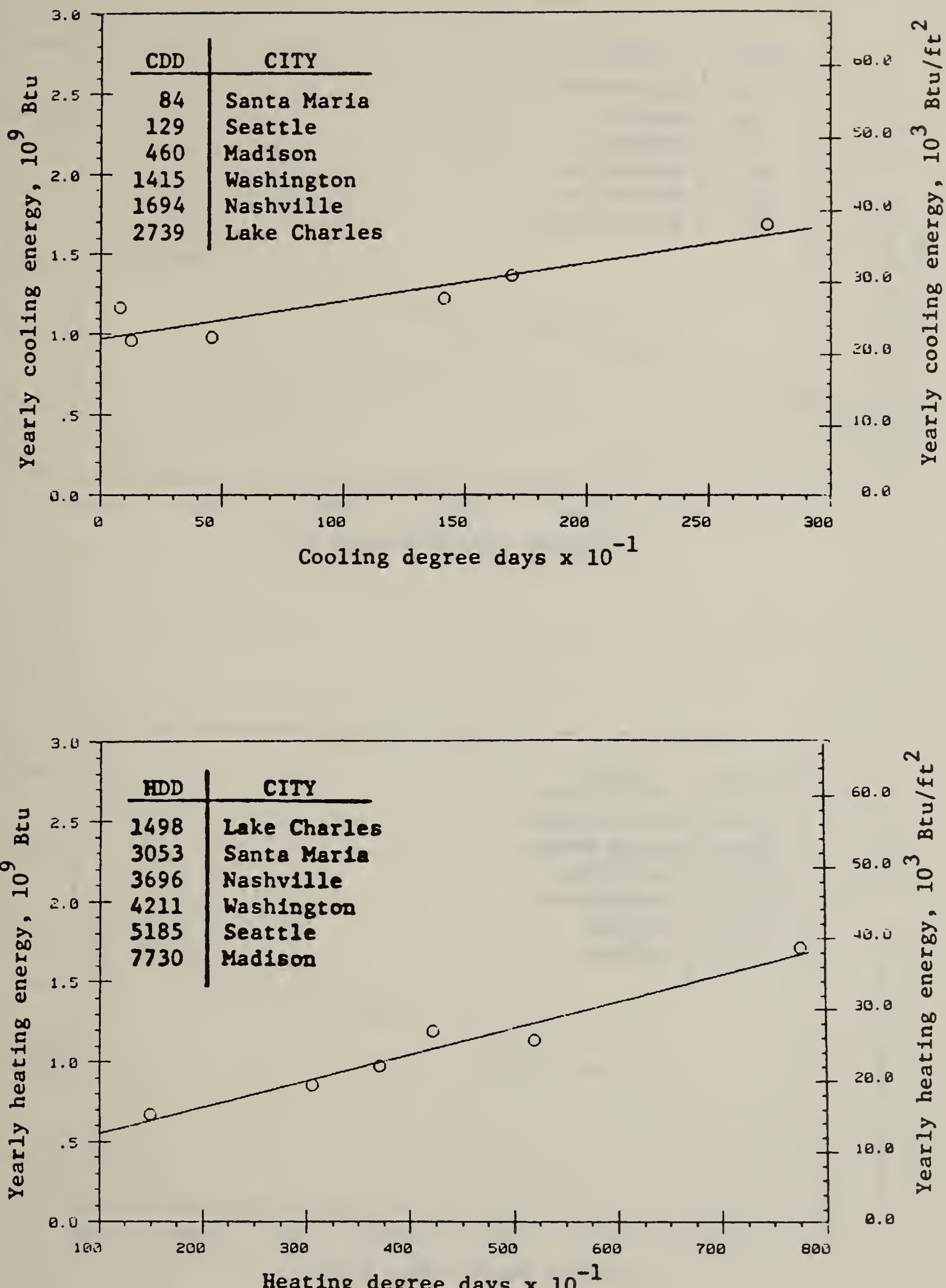
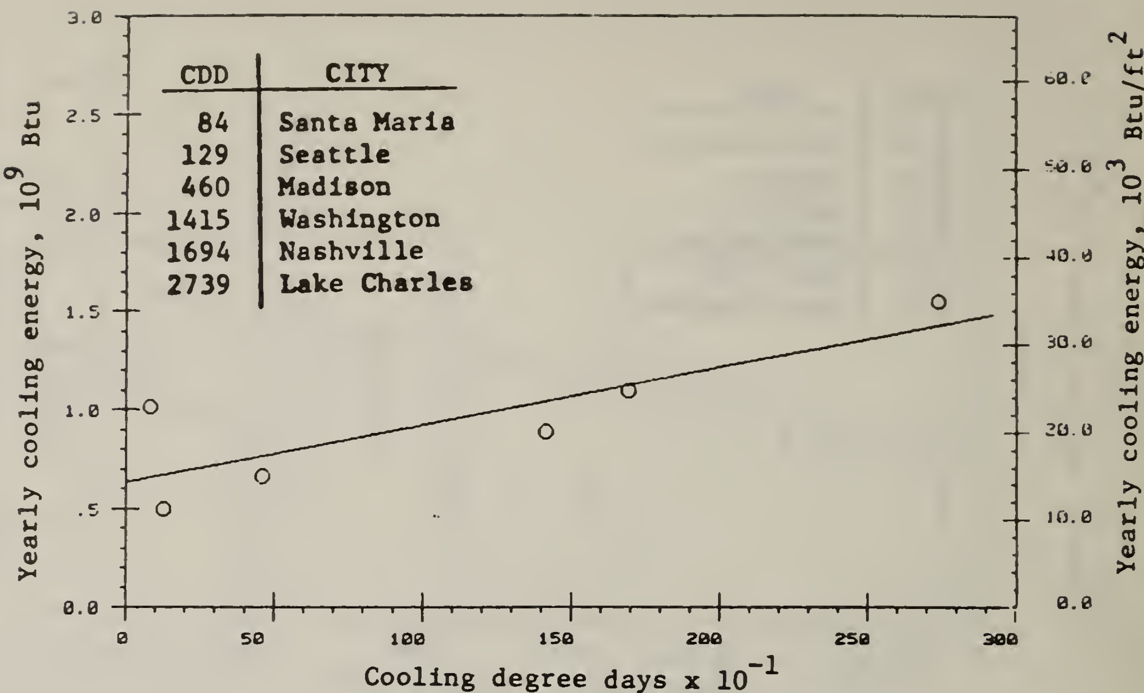


Figure 8. Cooling and heating energy consumption of case 1 (classrooms and offices) -- base reheat



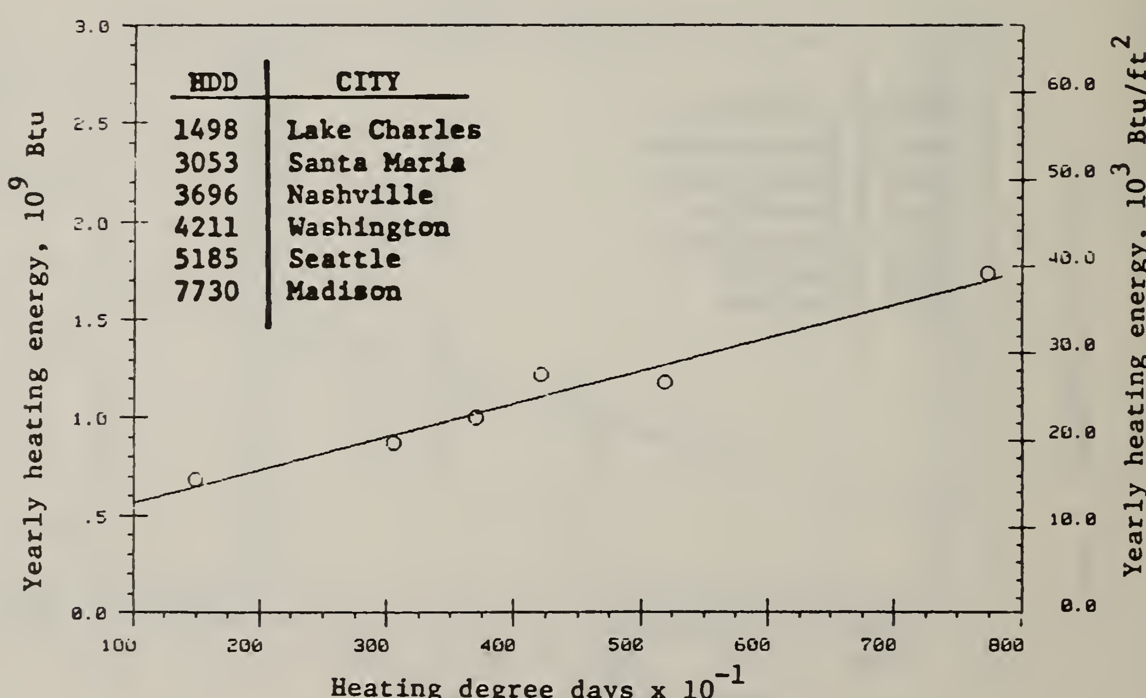
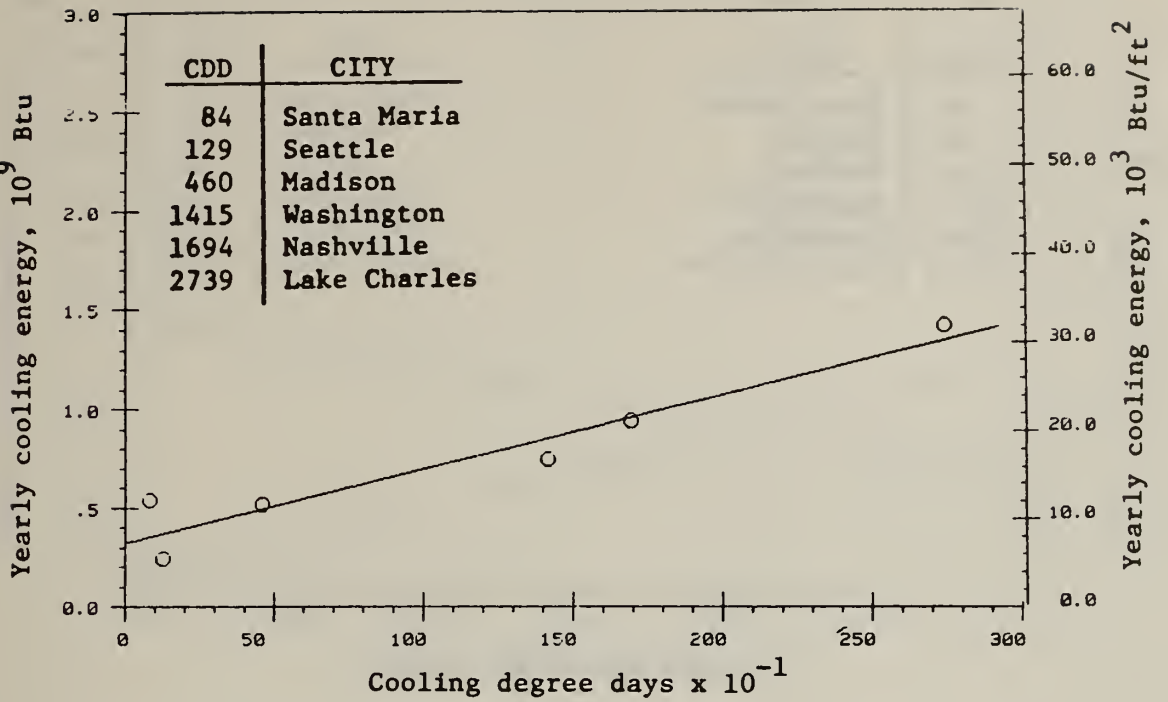


Figure 9. Cooling and heating energy consumption of case 2 (classrooms and offices) -- base reheat with temperature economy cycle



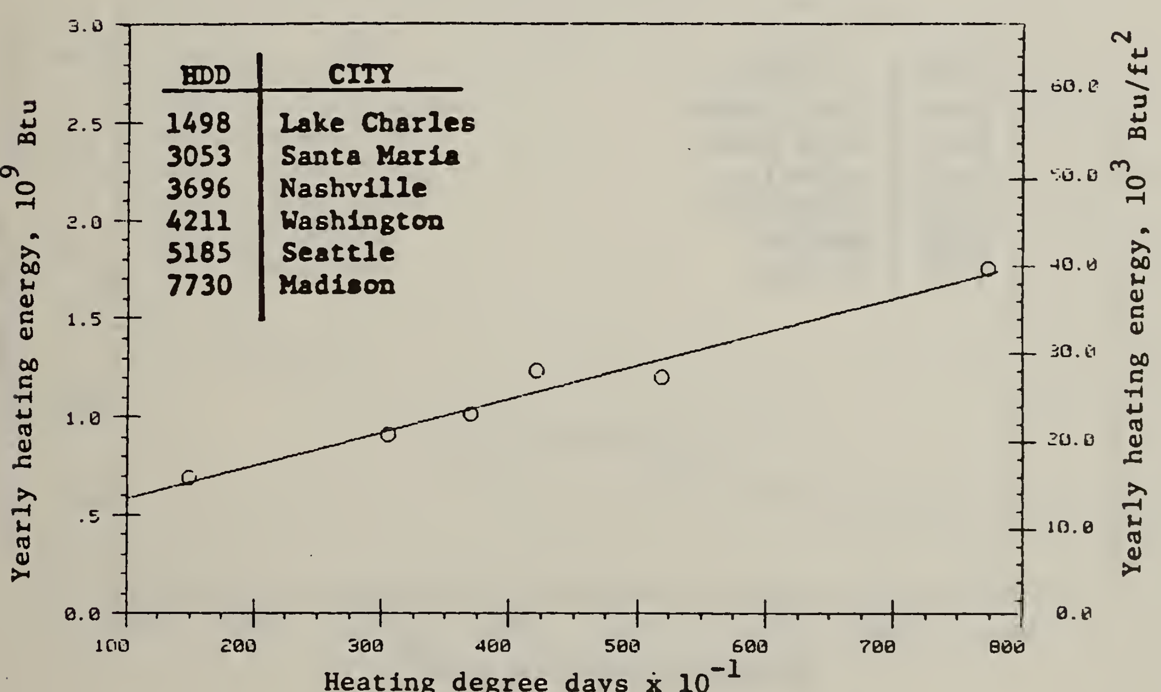
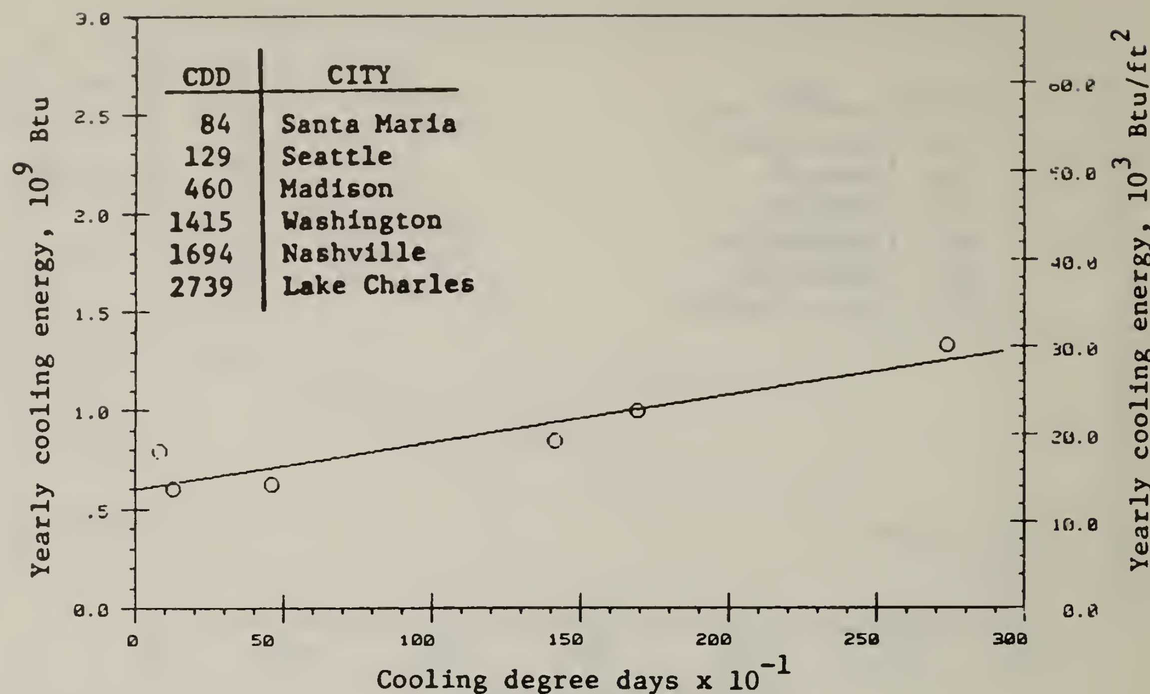


Figure 10. Cooling and heating energy consumption of case 3 (classrooms and offices) -- base reheat with enthalpy economy cycle



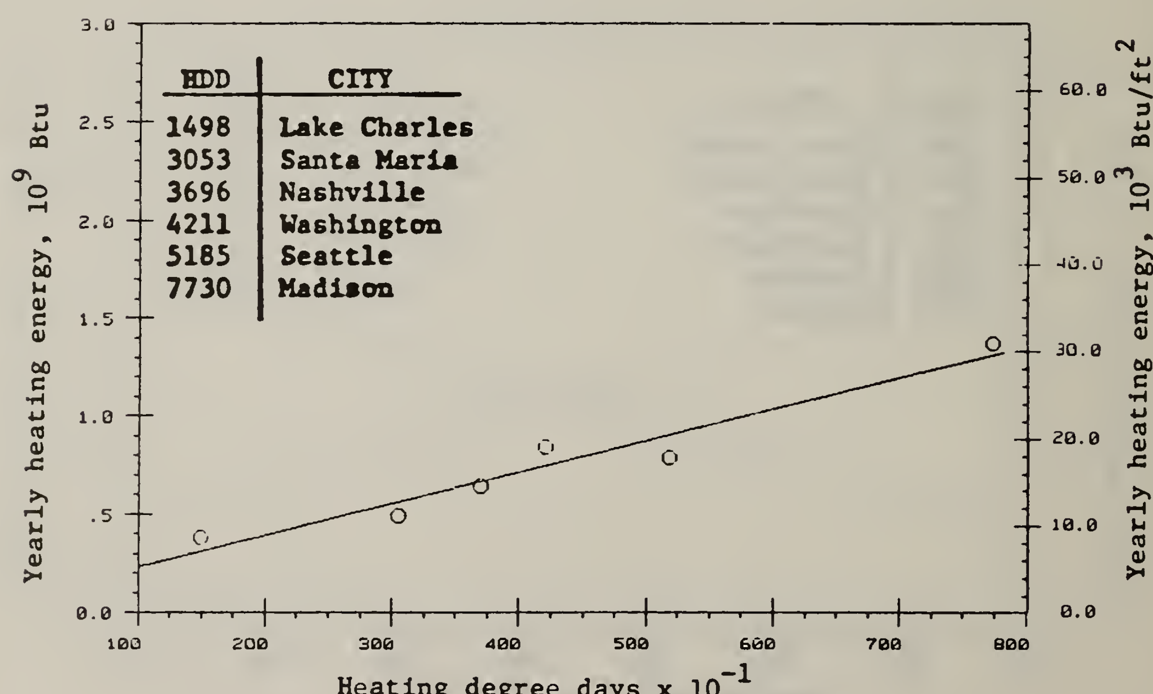
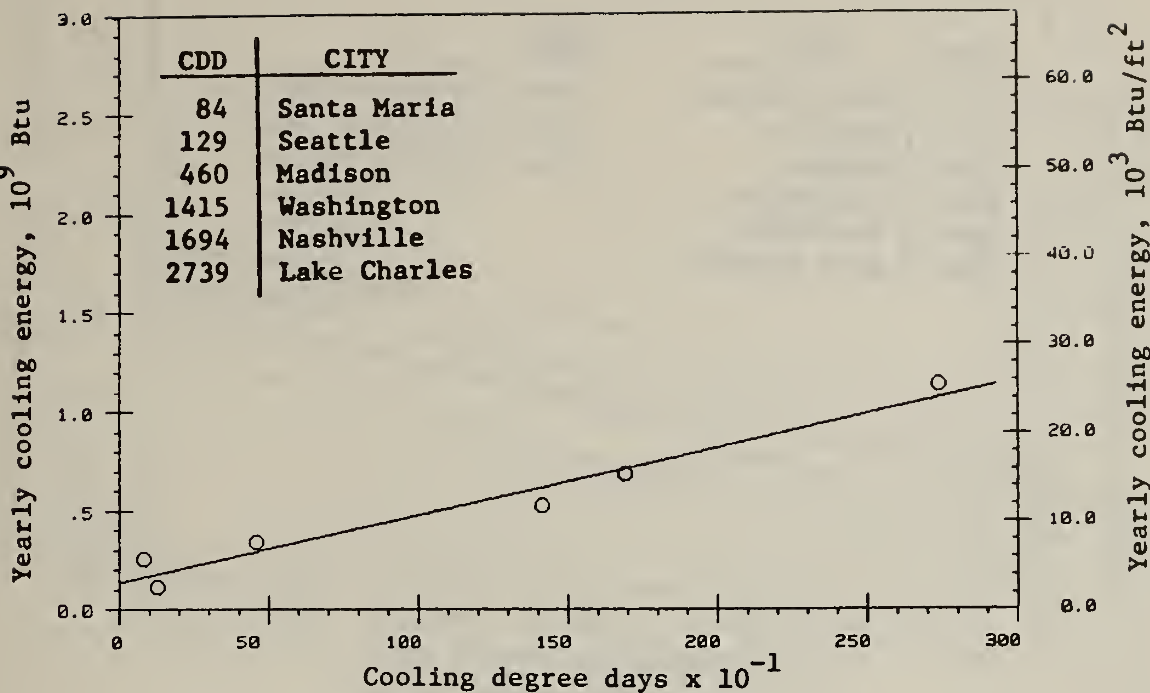


Figure 11. Cooling and heating energy consumption of case 4 (classrooms and offices) -- base reheat with supply air temperature reset by zone load demand



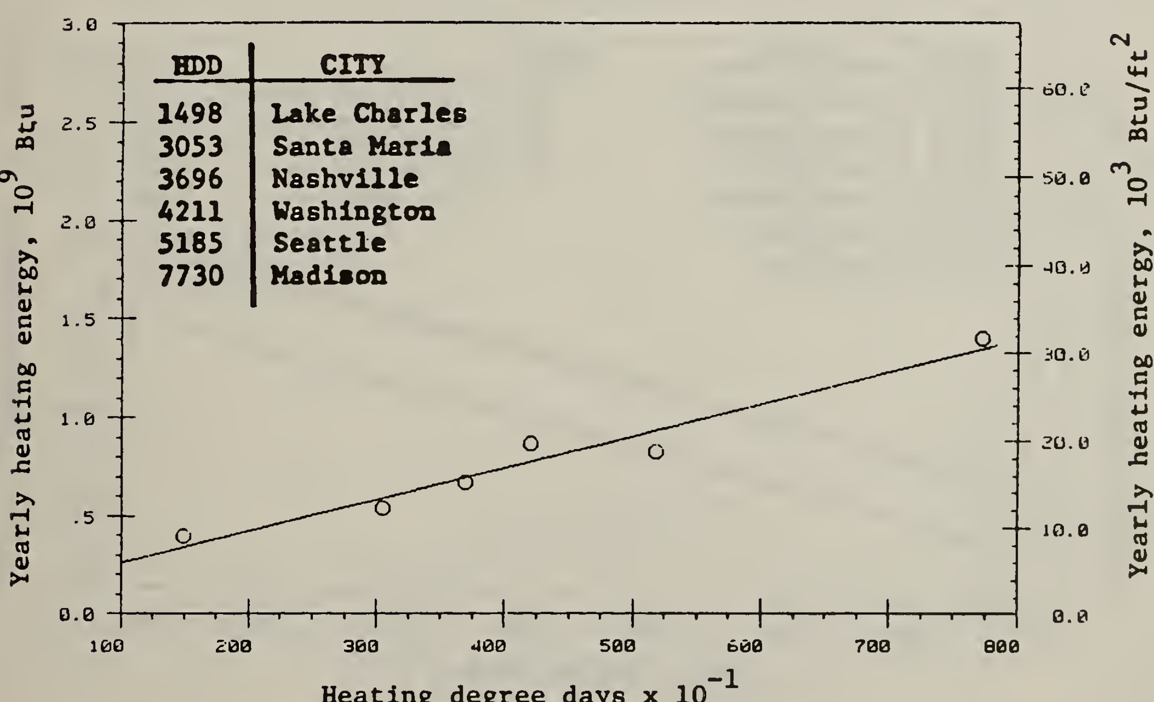
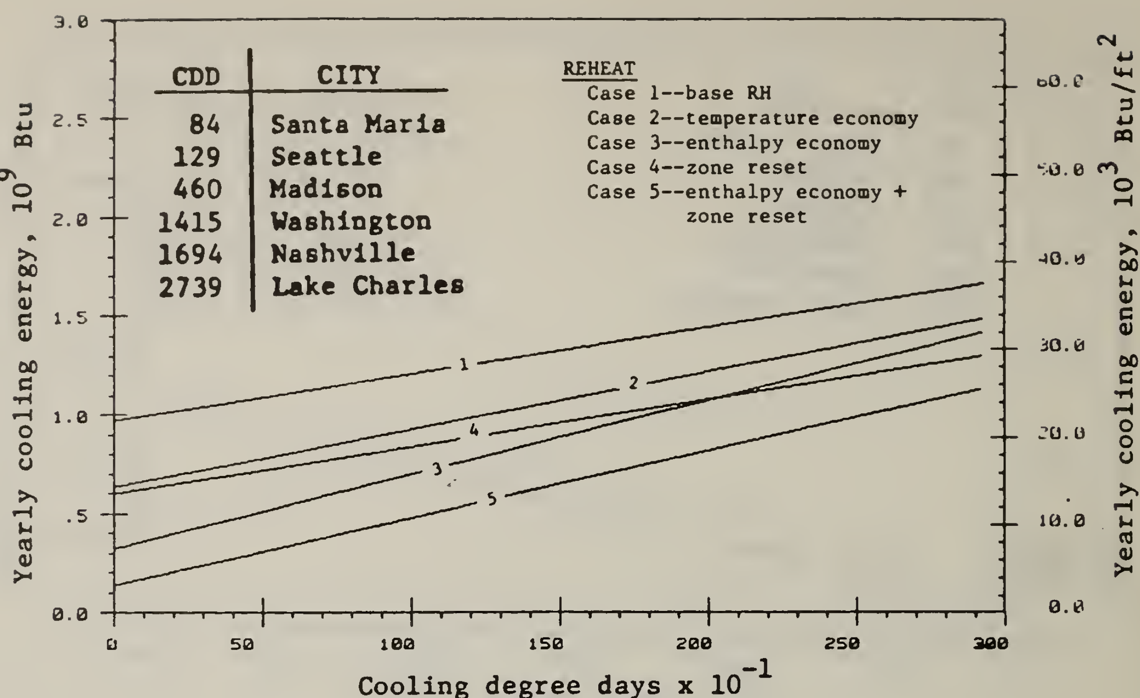


Figure 12. Cooling and heating energy consumption of case 5 (classrooms and offices) -- base reheat with enthalpy economy and supply air temperature reset by zone load demand



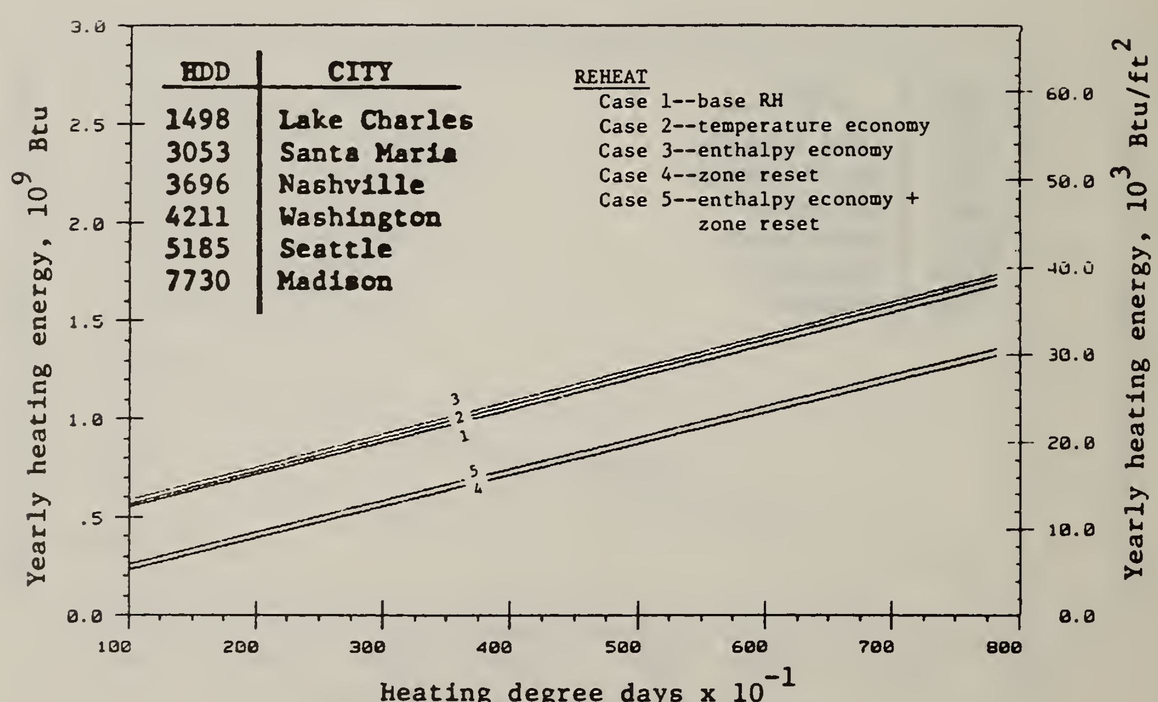
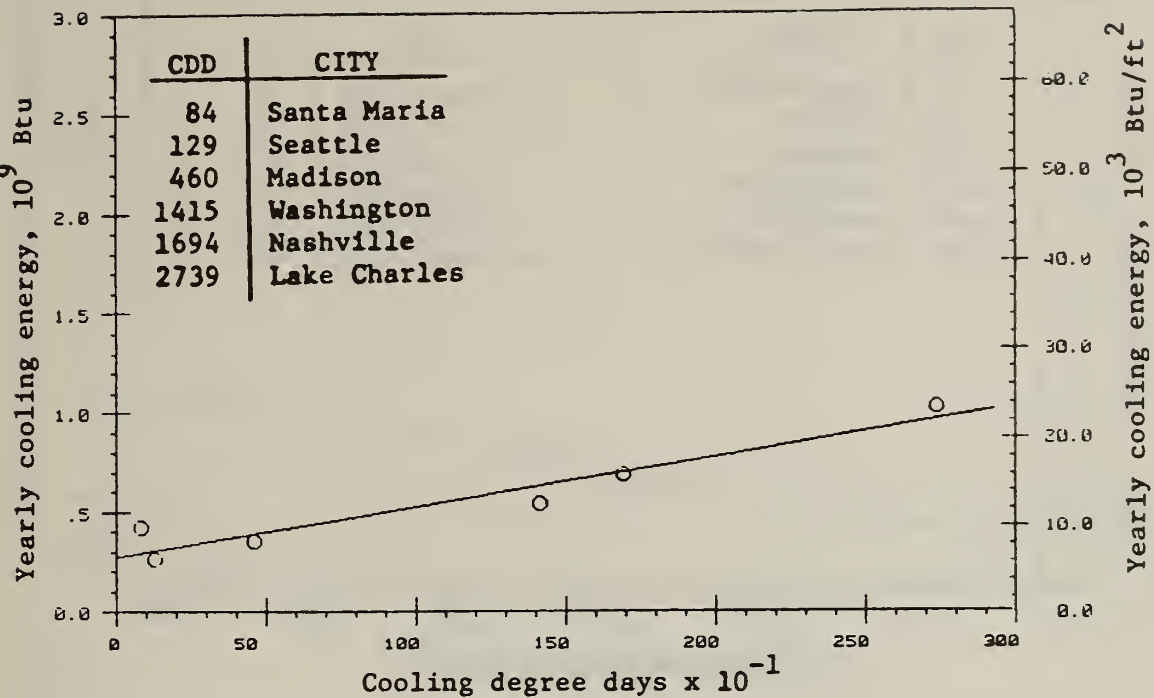


Figure 13. Cooling and heating energy consumption of cases 1 through 5 (classrooms and offices) -- all reheat cases



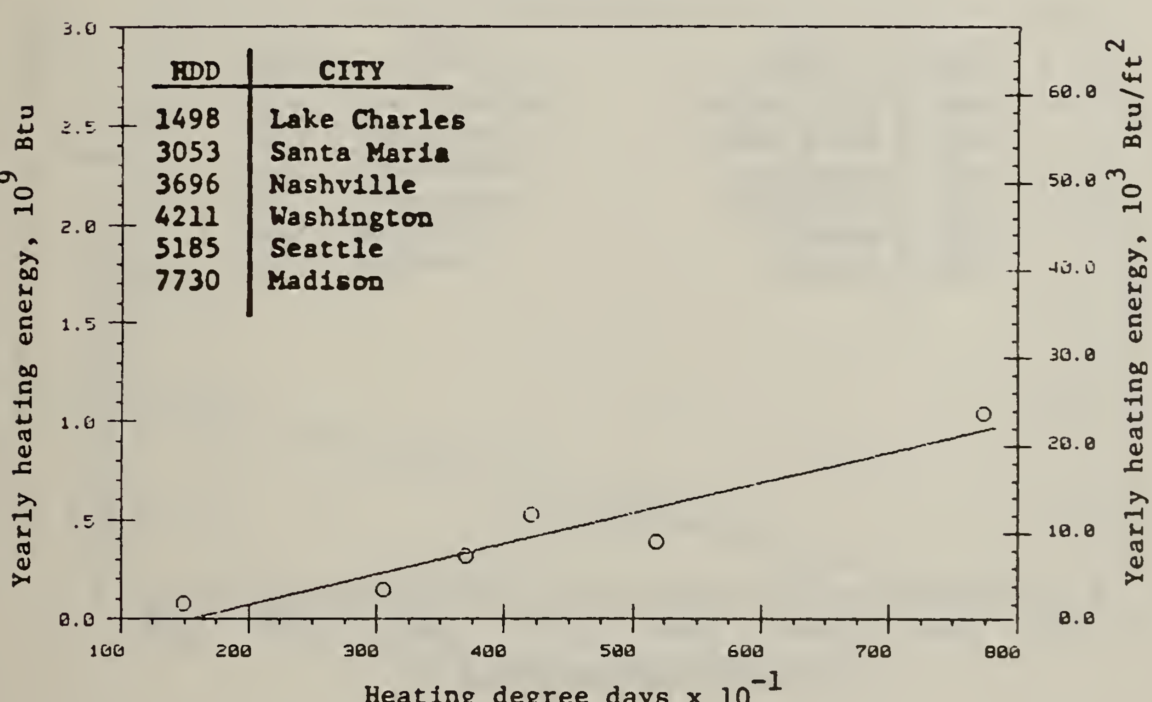
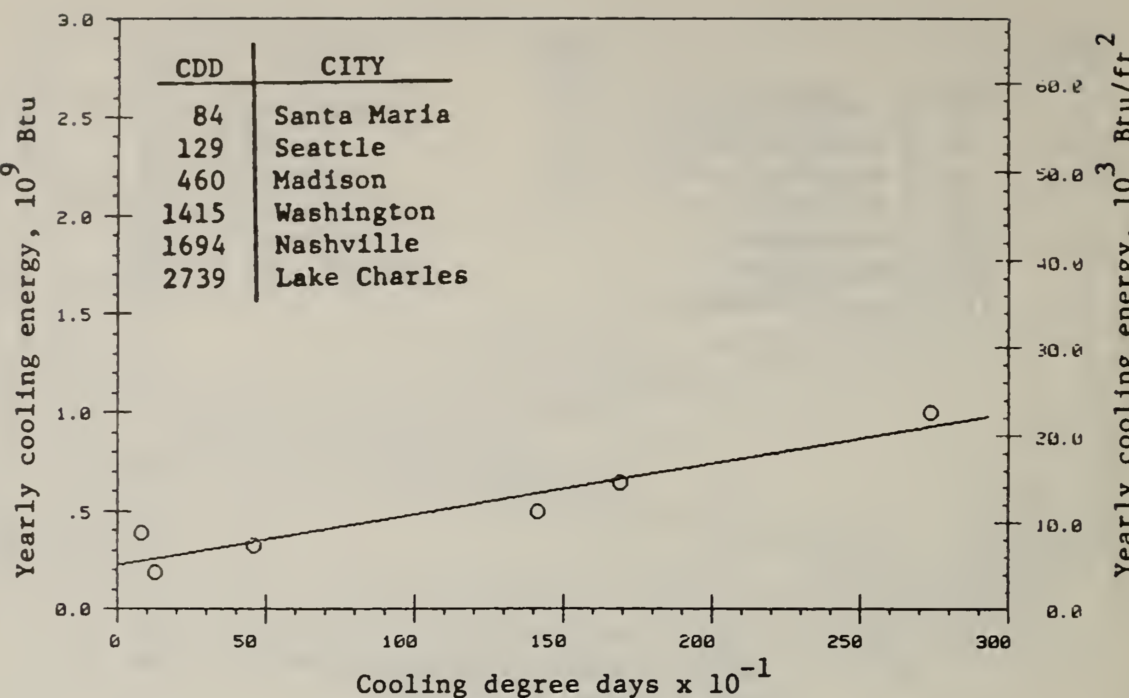


Figure 14. Cooling and heating energy consumption of case 6 (classrooms and offices) -- base variable air volume



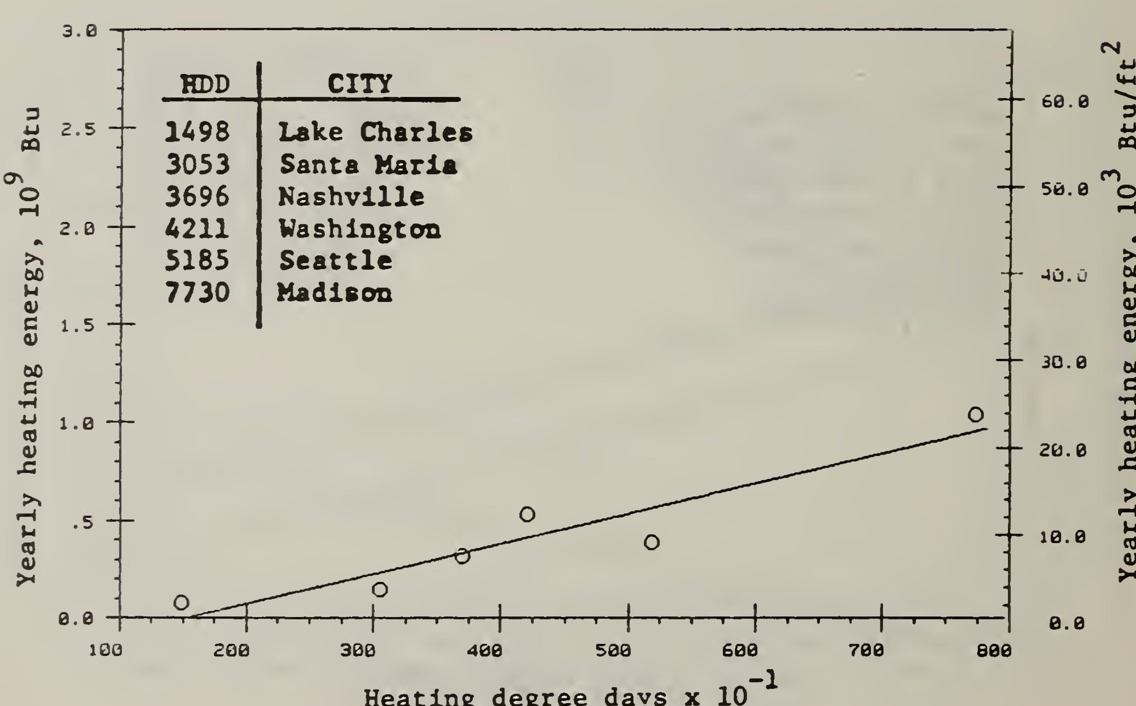


Figure 15. Cooling and heating energy consumption of case 7 (classrooms and offices) -- base variable air volume with temperature economy cycle

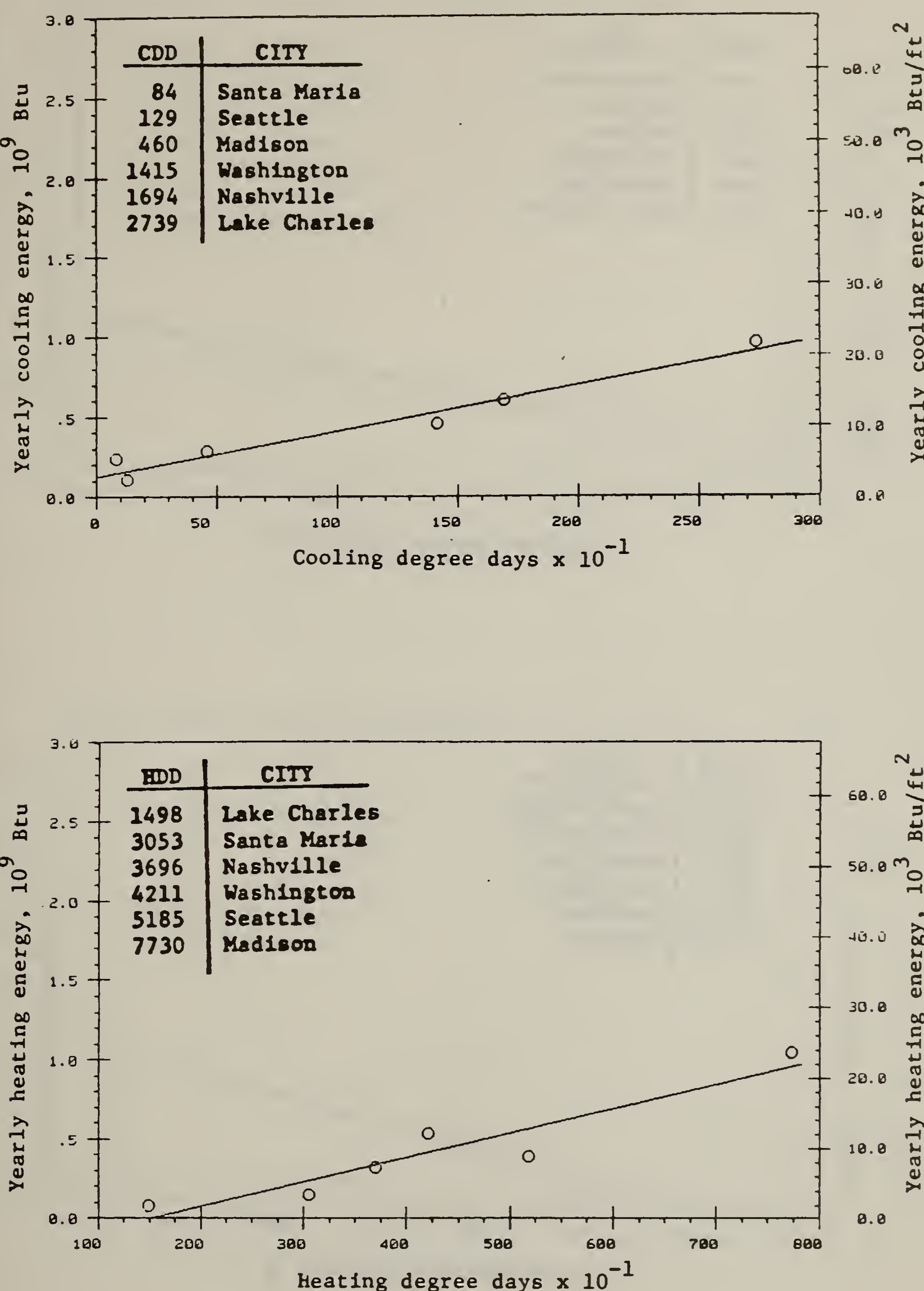
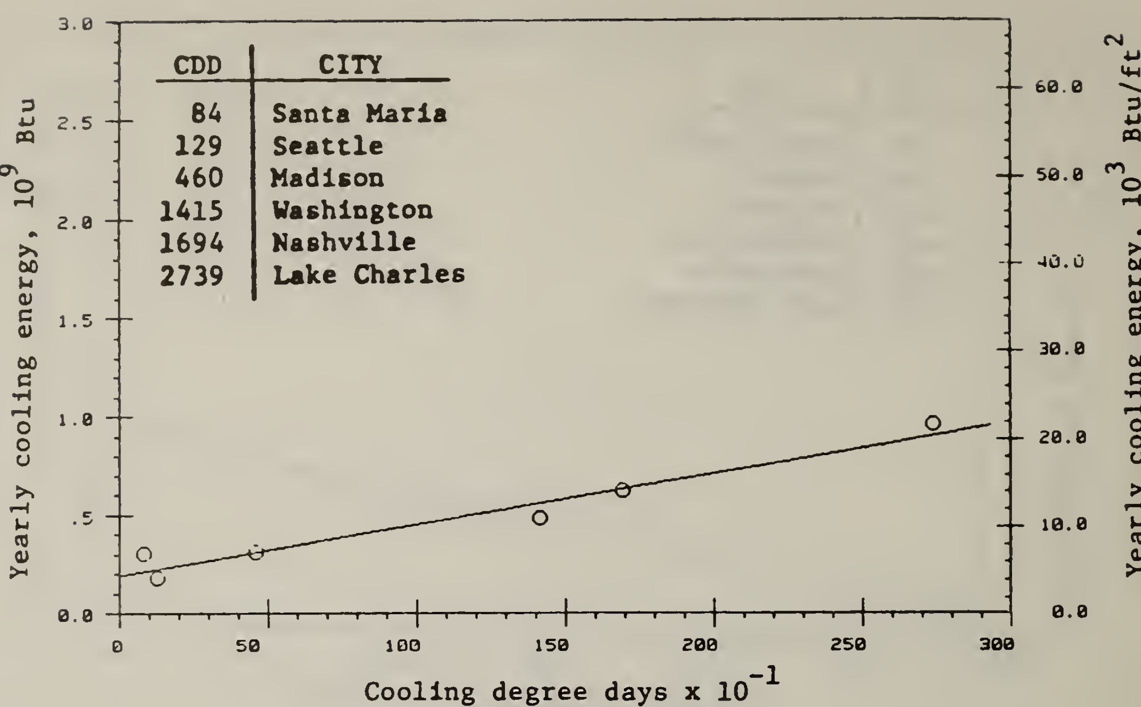


Figure 16. Cooling and heating energy consumption of case 8 (classrooms and offices) -- base variable air volume with enthalpy economy cycle



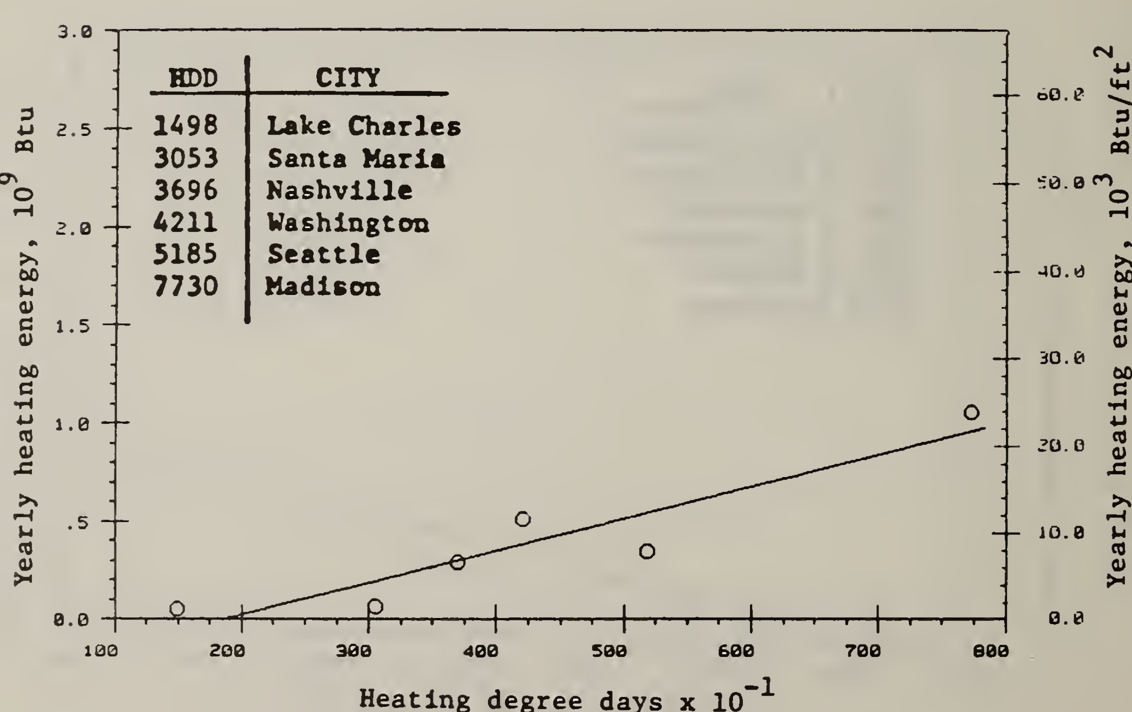
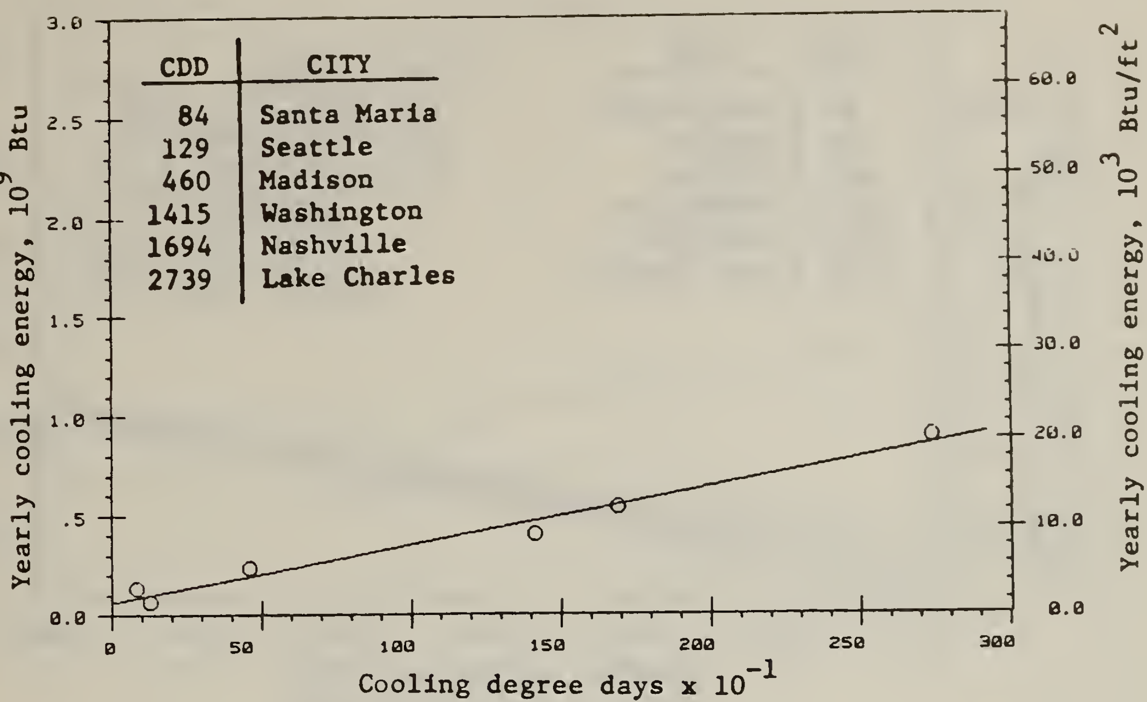


Figure 17. Cooling and heating energy consumption of case 9 (classrooms and offices) -- base variable air volume with supply air temperature reset by zone load demand



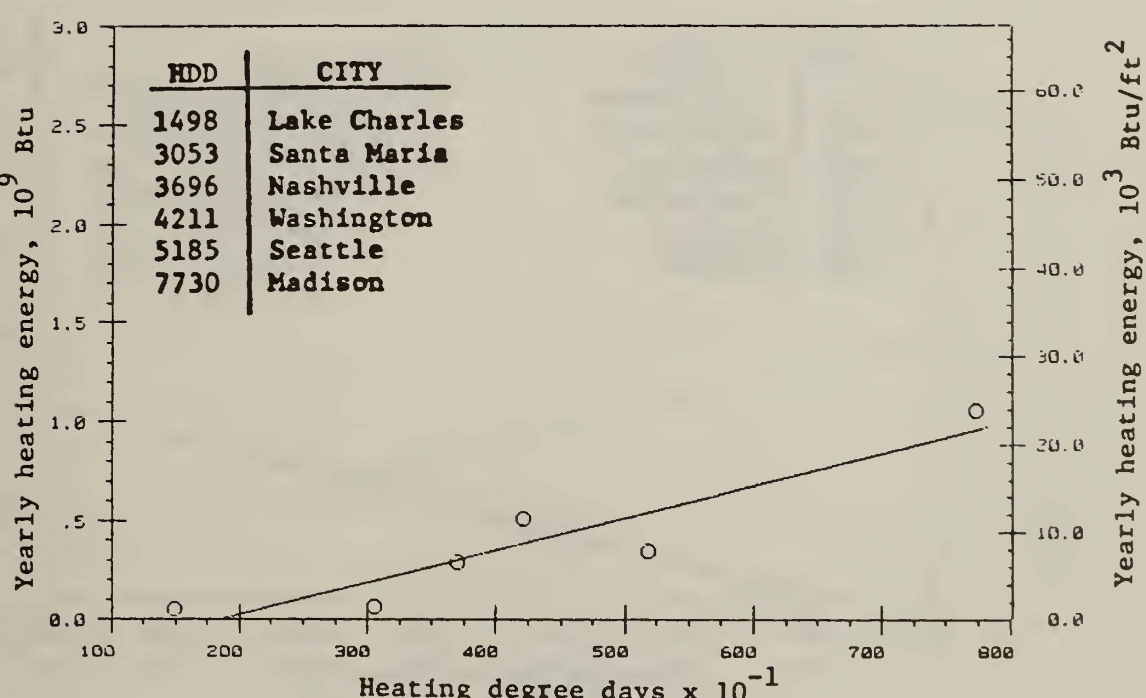
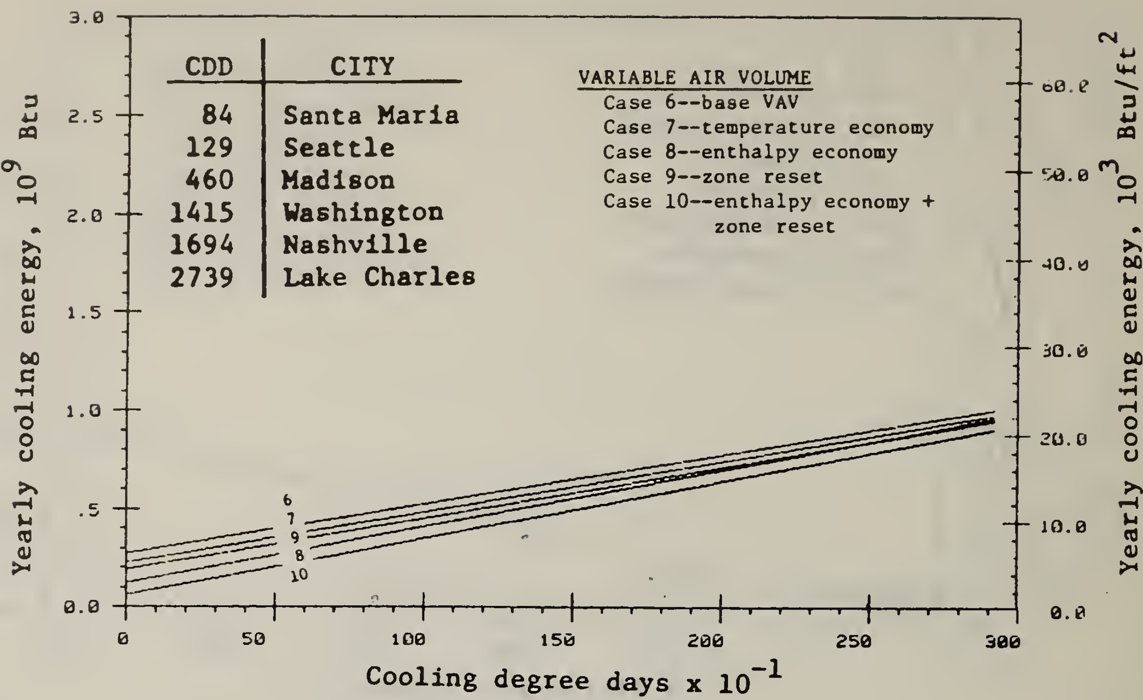


Figure 18. Cooling and heating energy consumption of case 10 (classrooms and offices) -- base variable air volume with enthalpy economy cycle and supply air temperature reset by zone load demand



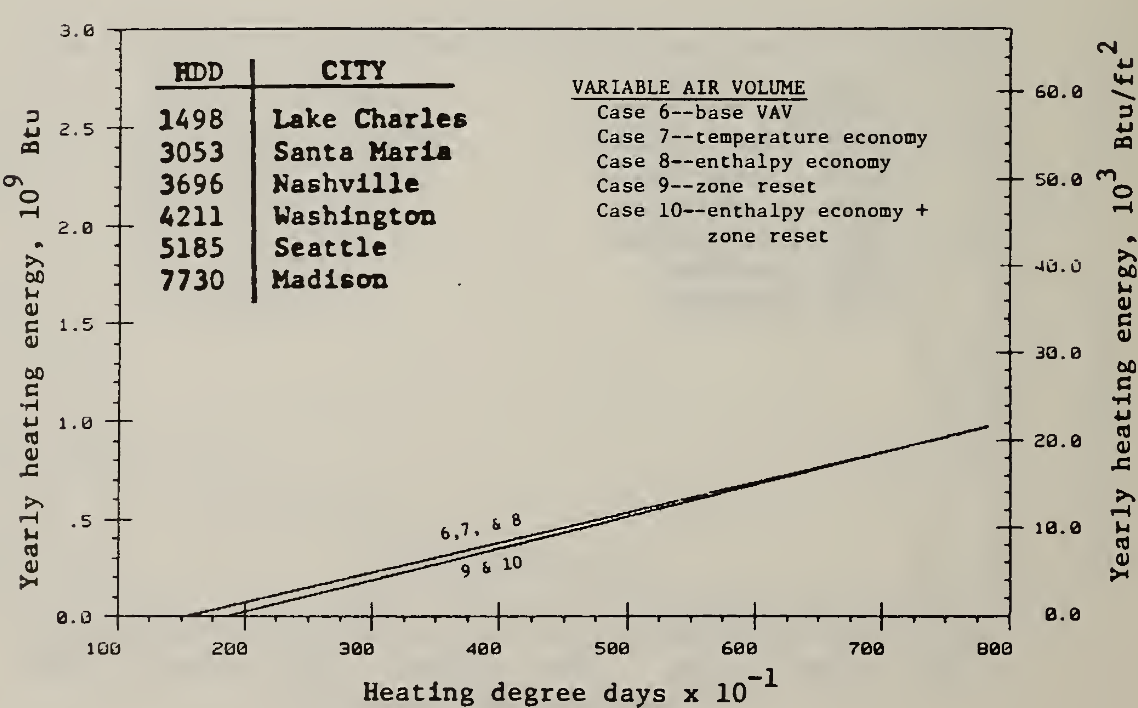
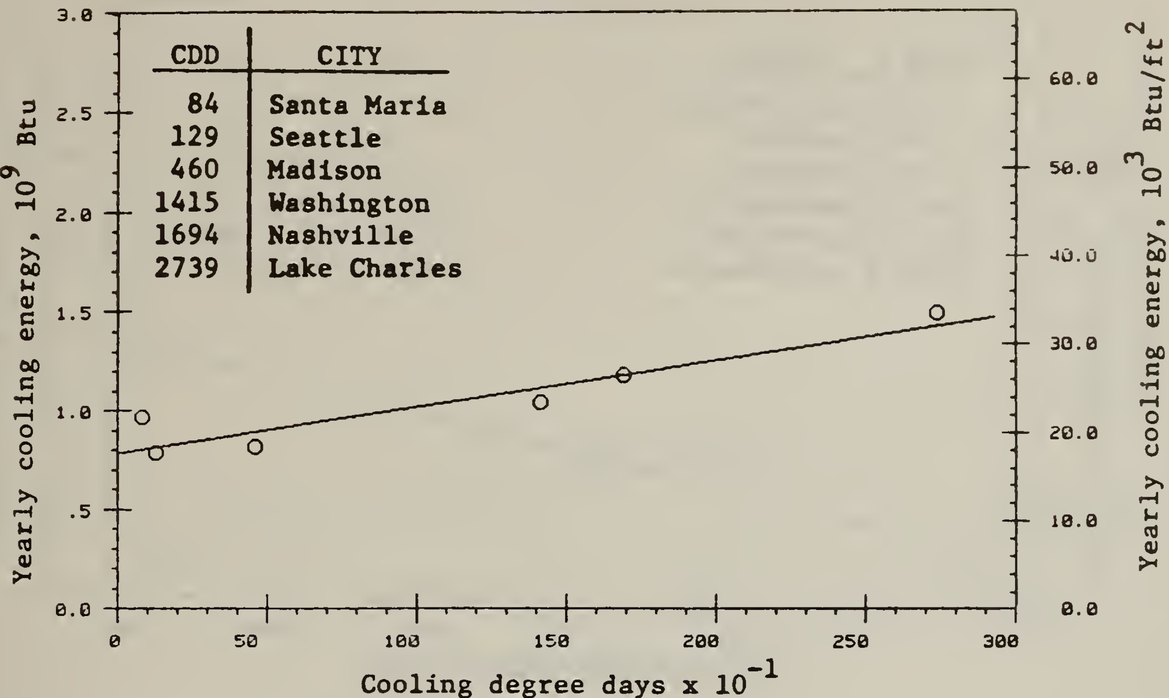


Figure 19. Cooling and heating energy consumption of cases 6 through 10 (classrooms and offices) -- all variable air volume cases



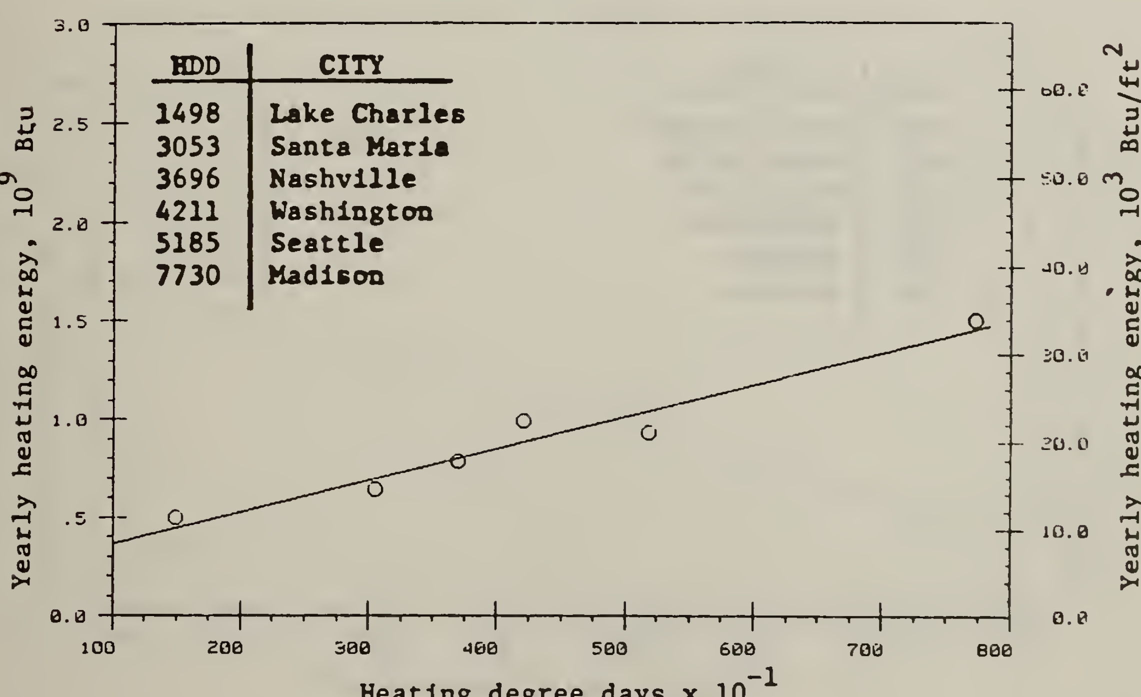


Figure 20. Cooling and heating energy consumption of case 11 (classrooms and offices) -- base dual-duct

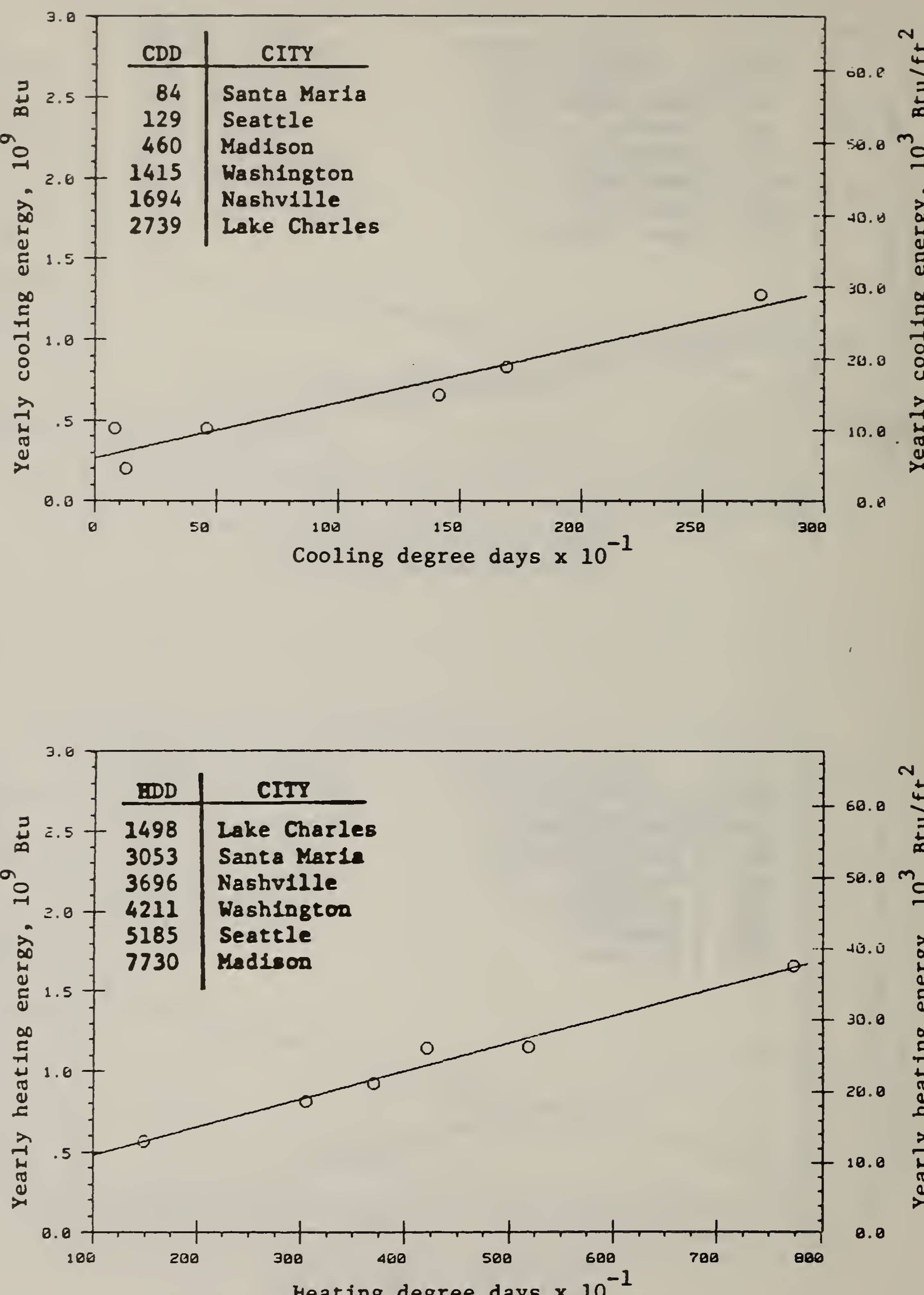
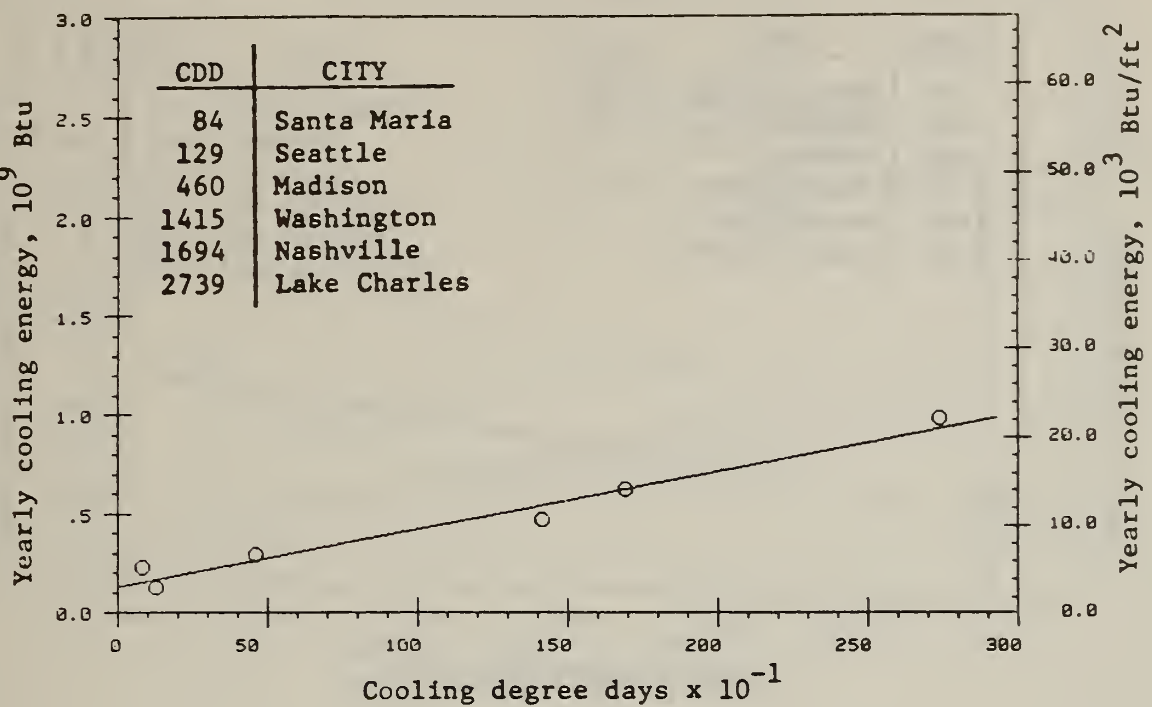


Figure 21. Cooling and heating energy consumption of case 12 (classrooms and offices) -- base dual-duct with enthalpy economy cycle



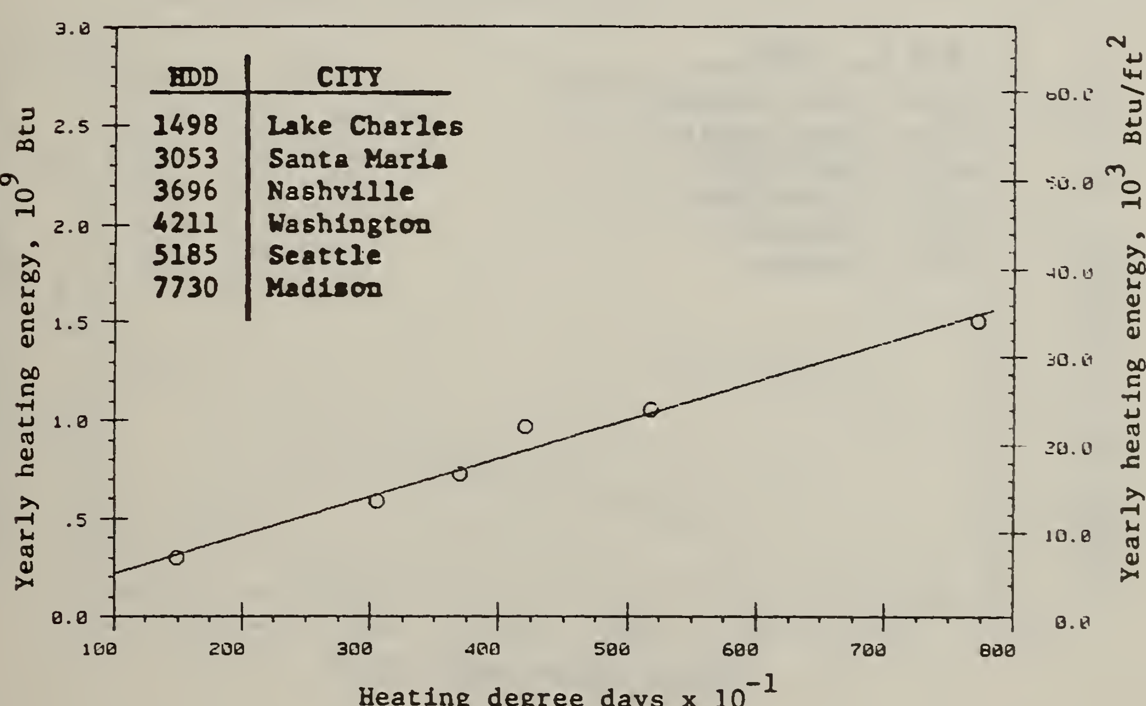
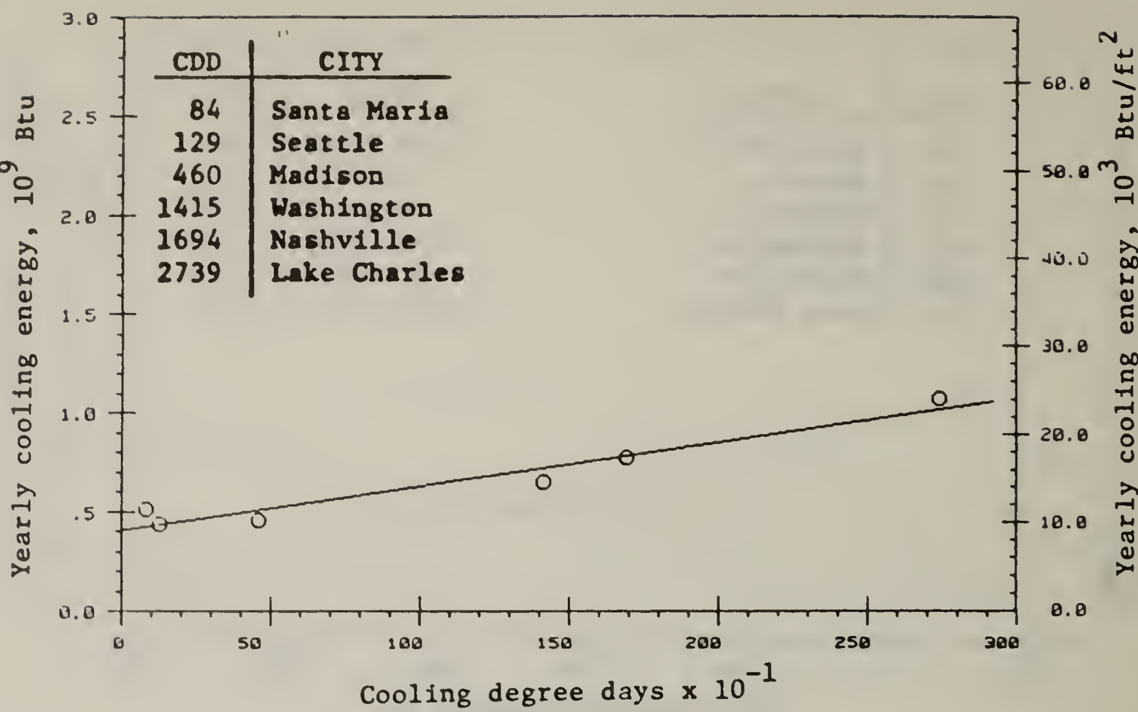


Figure 22. Cooling and heating energy consumption of case 13 (classrooms and offices) -- base dual-duct with enthalpy economy cycle and hot air temperature reset



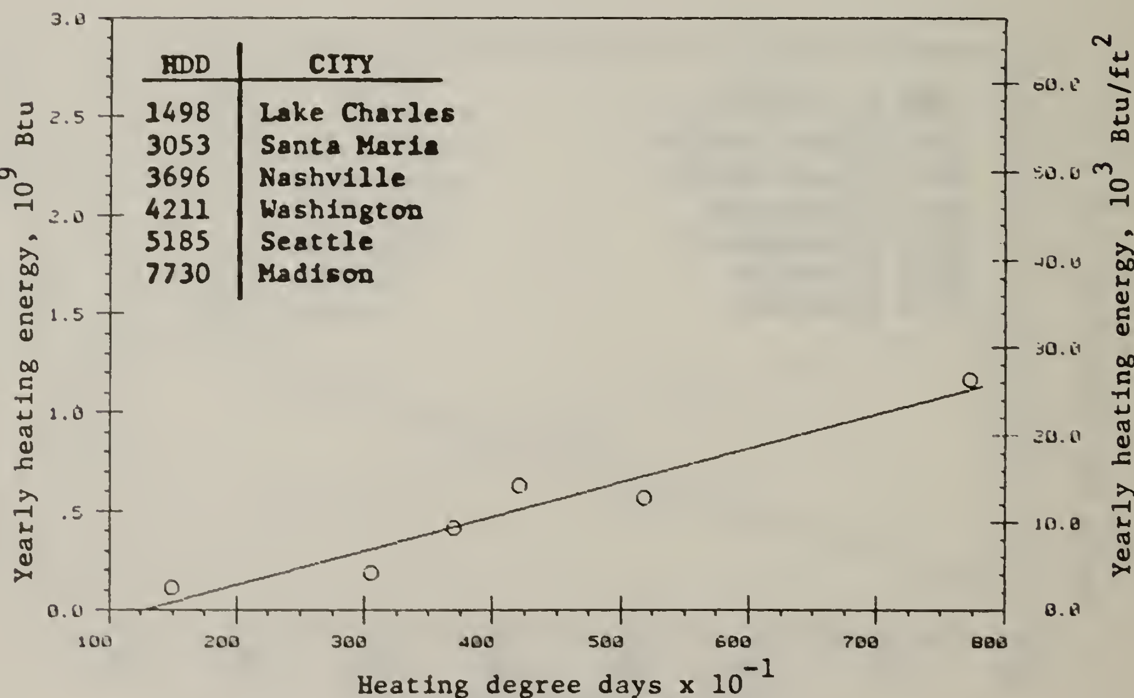
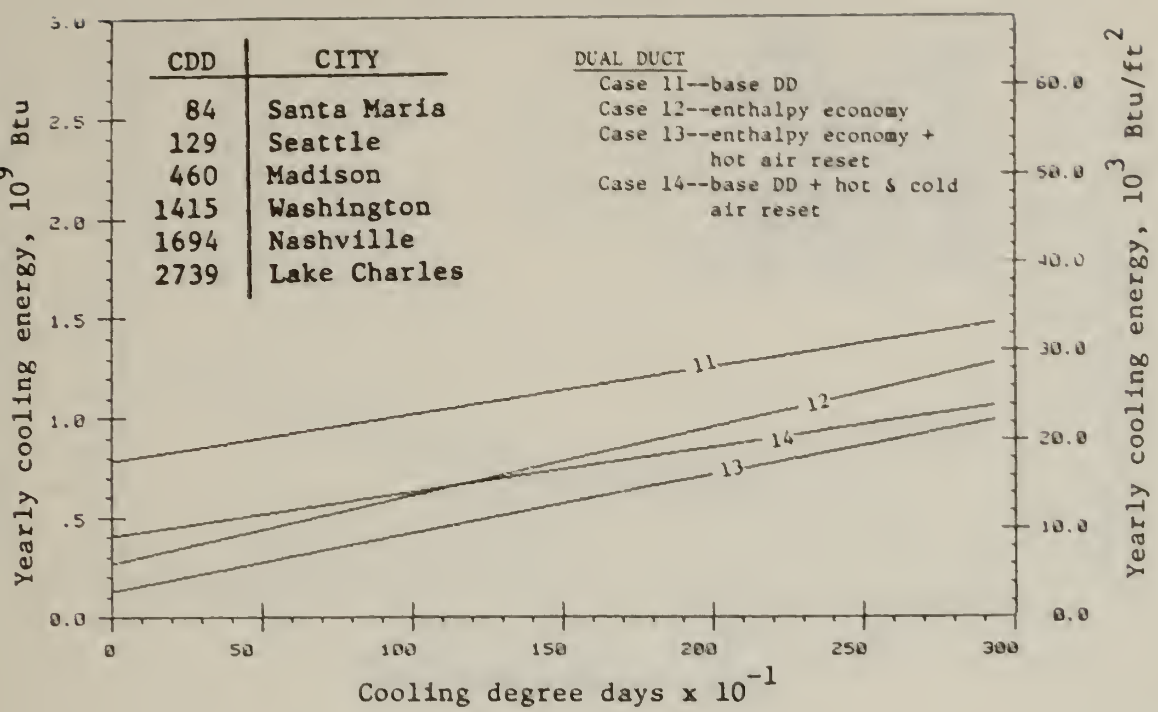


Figure 23. Cooling and heating energy consumption of case 14 (classrooms and offices) -- base dual-duct with hot and cold air temperature reset



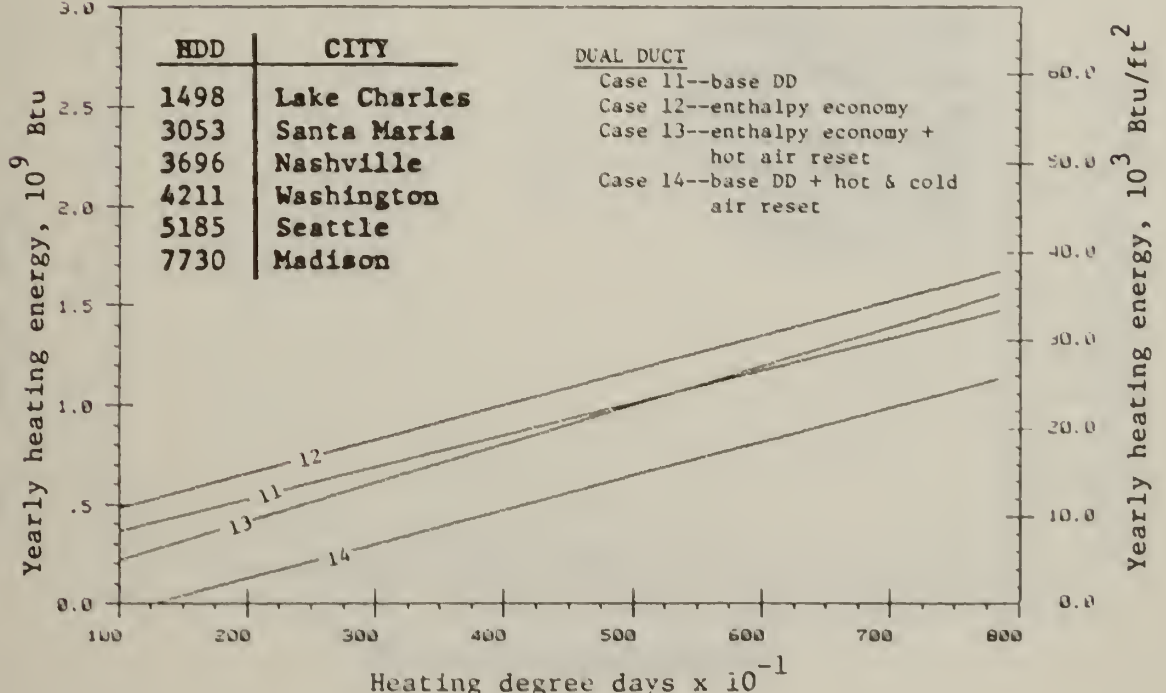
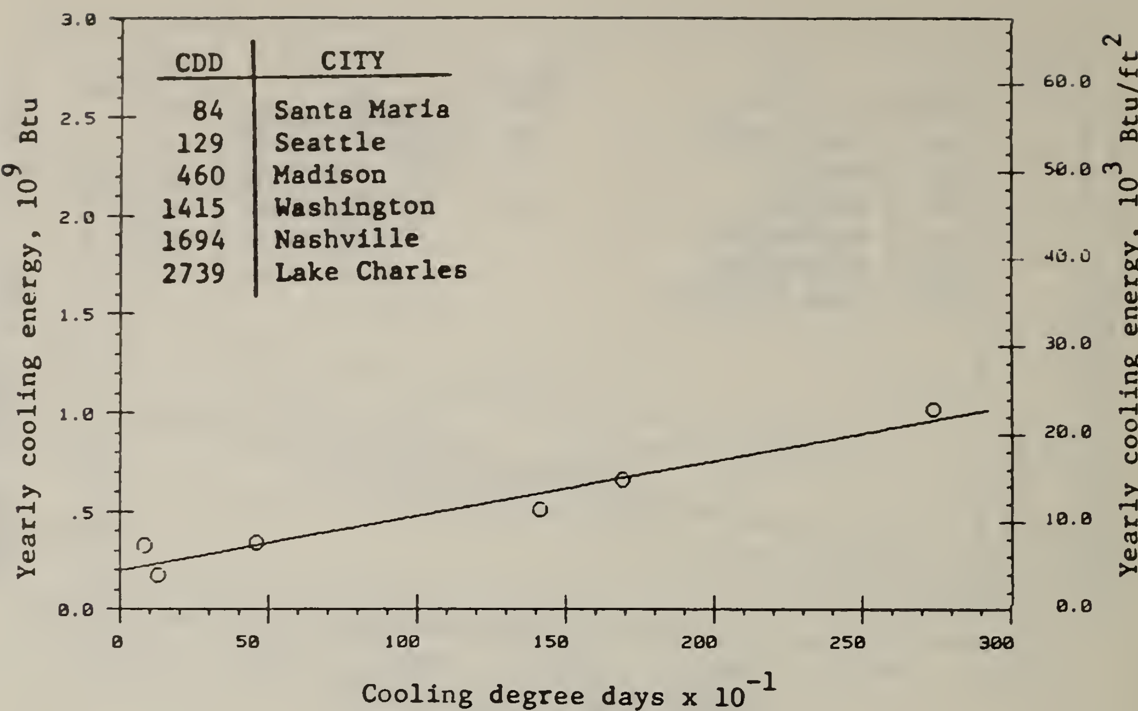


Figure 24. Cooling and heating energy consumption of cases 11 through 14 (classrooms and offices) -- all dual-duct cases



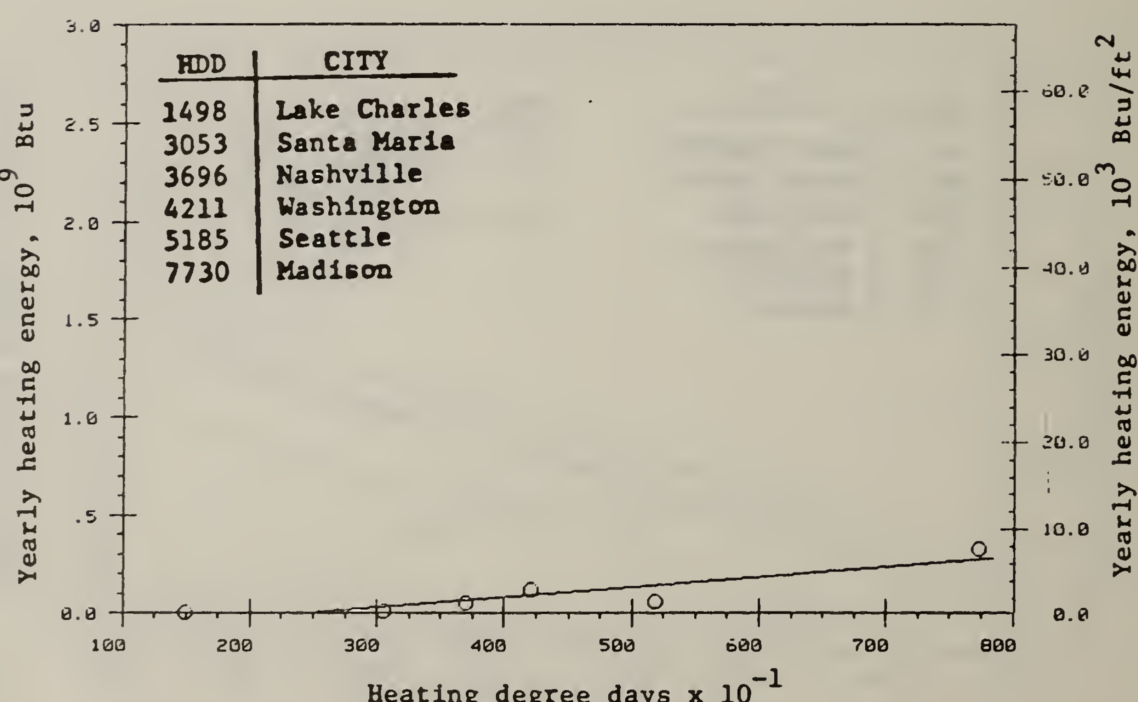
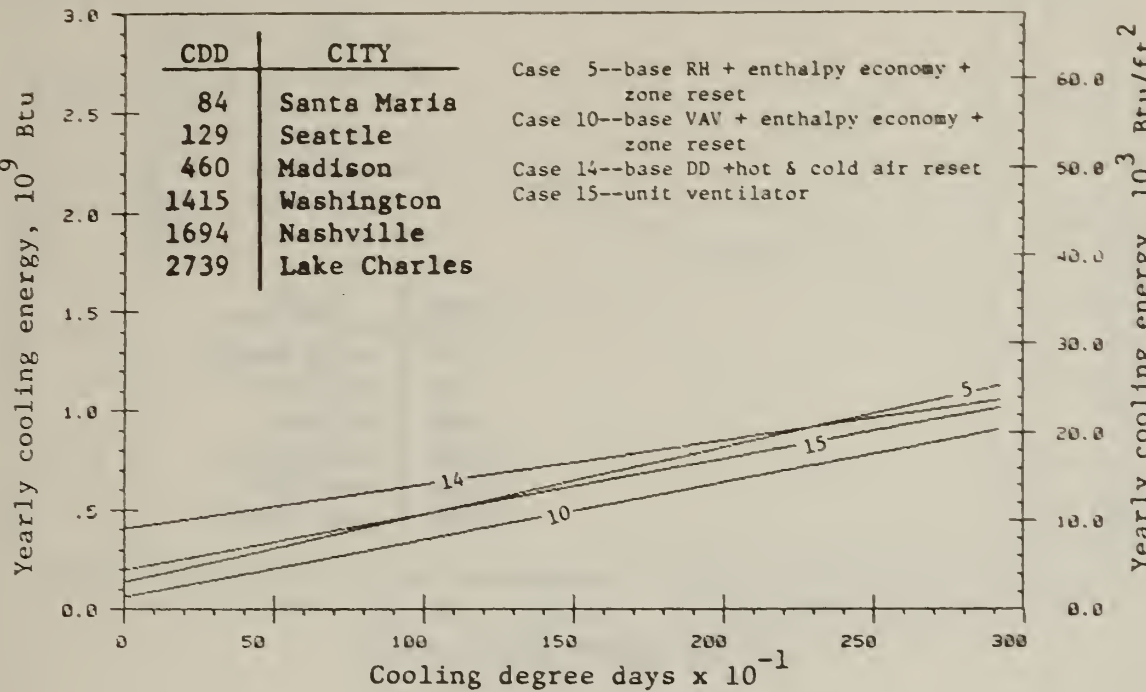


Figure 25. Cooling and heating energy consumption of case 15 (classrooms and offices) -- unit ventilator system



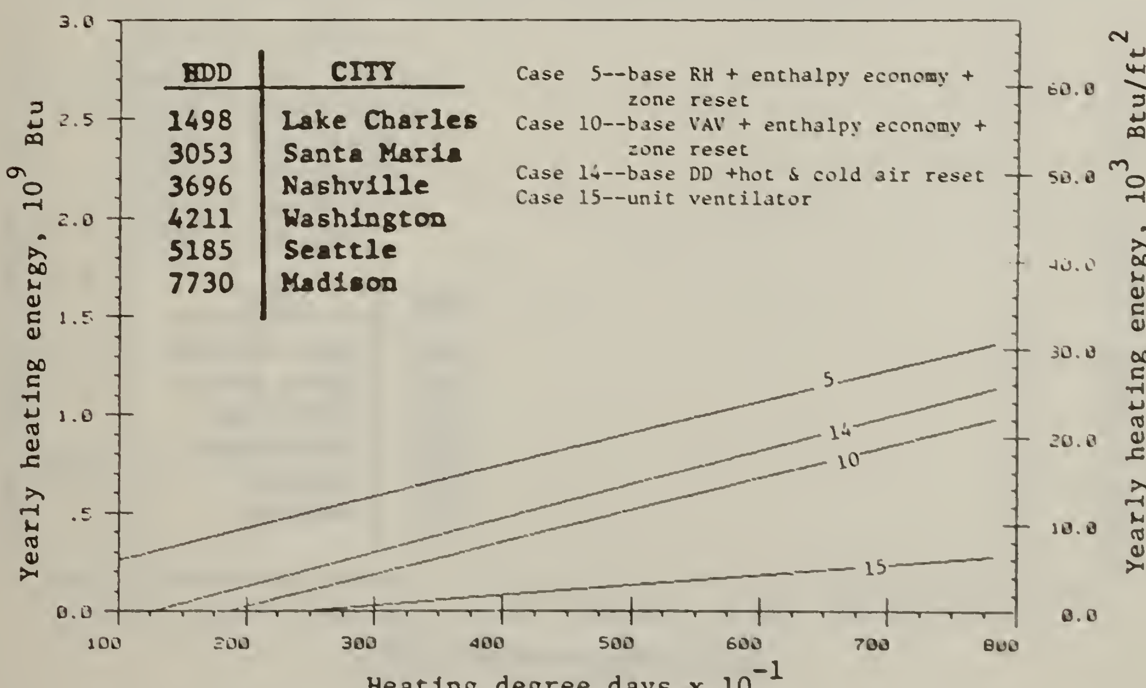
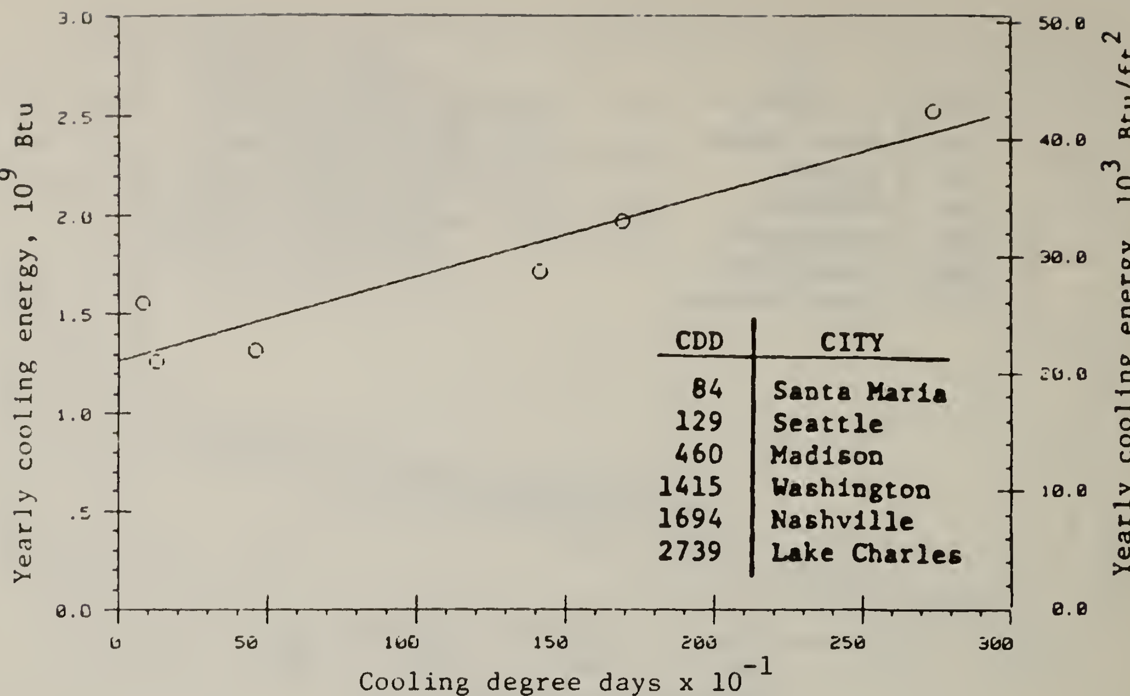


Figure 26. Cooling and heating energy consumption of cases 5, 10, 14, and 15 (classrooms and offices)



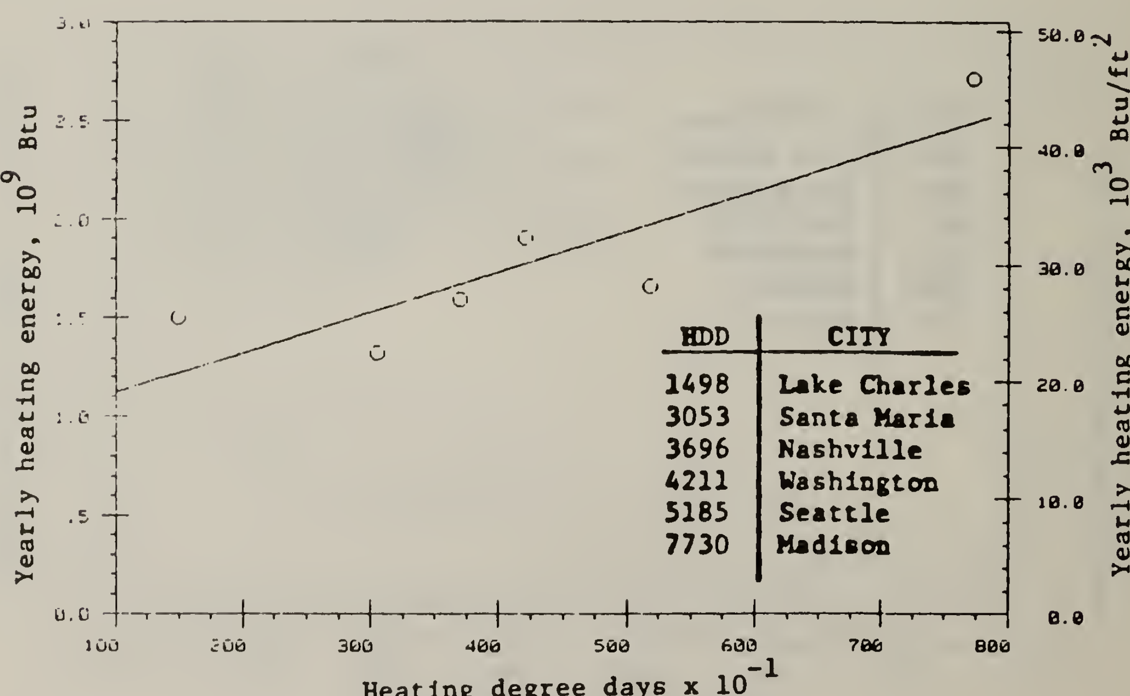
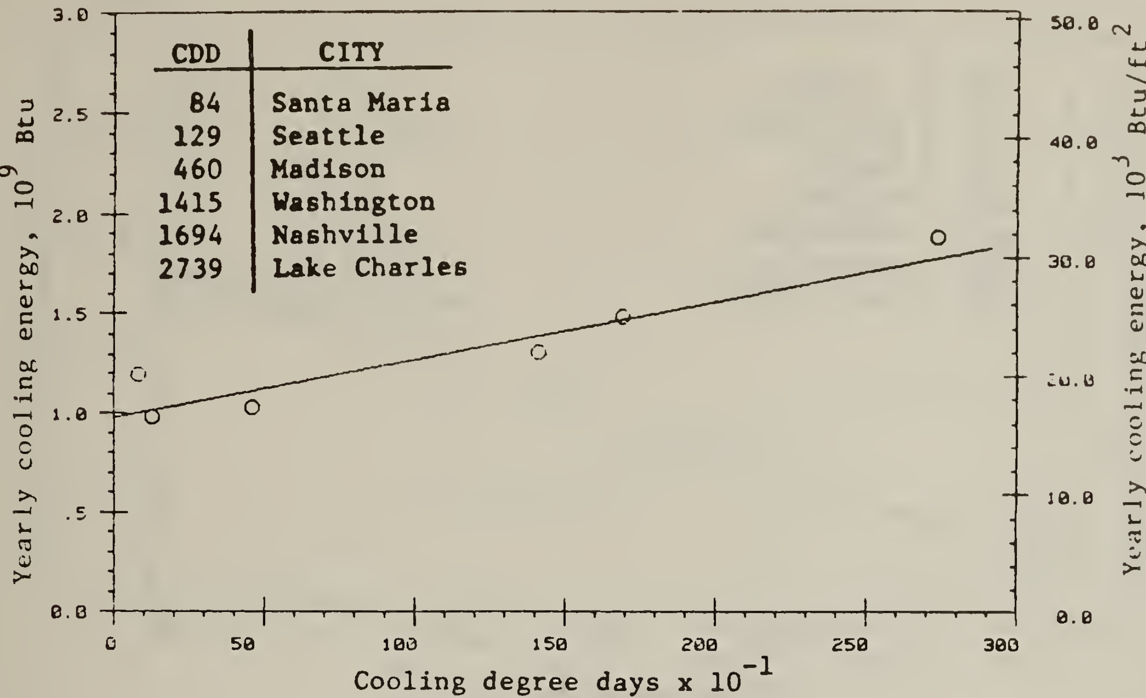


Figure 27. Cooling and heating energy consumption of case 16 (entire school) -- case 1 for classrooms and offices, base systems for non-classroom/office areas, all systems on for 10 hours a day



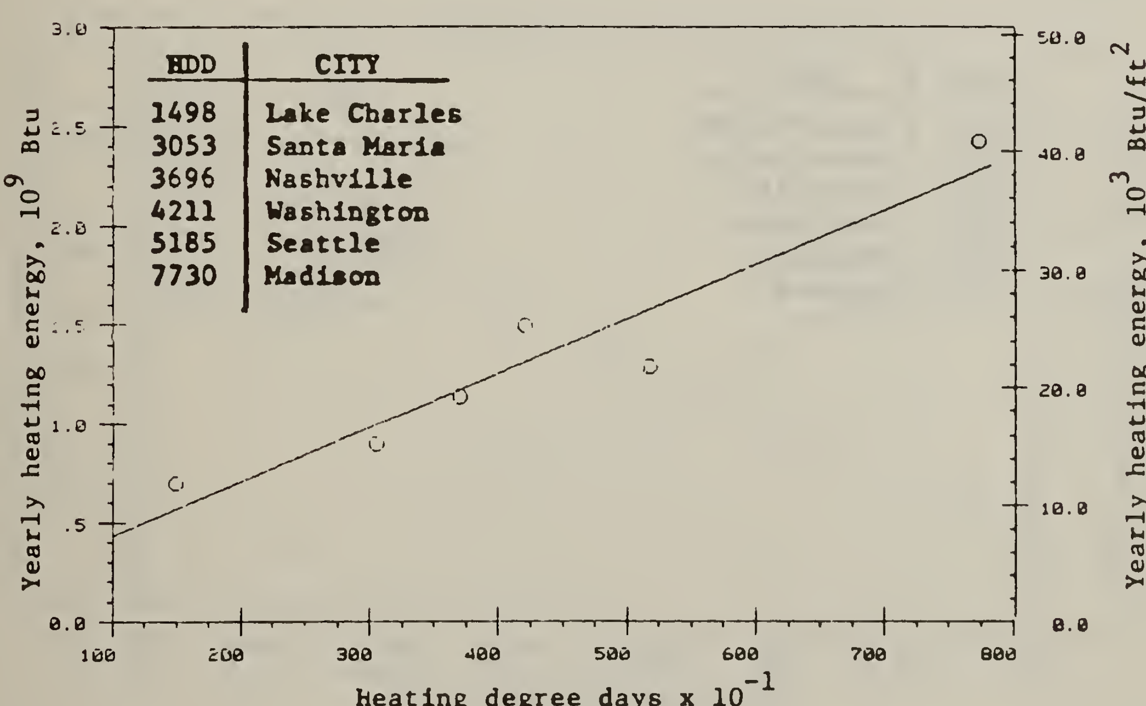


Figure 28. Cooling and heating energy consumption of case 17 (entire school) -- case 1 for classrooms and offices, base systems for non-classroom/office areas, all systems on according to occupancy schedules

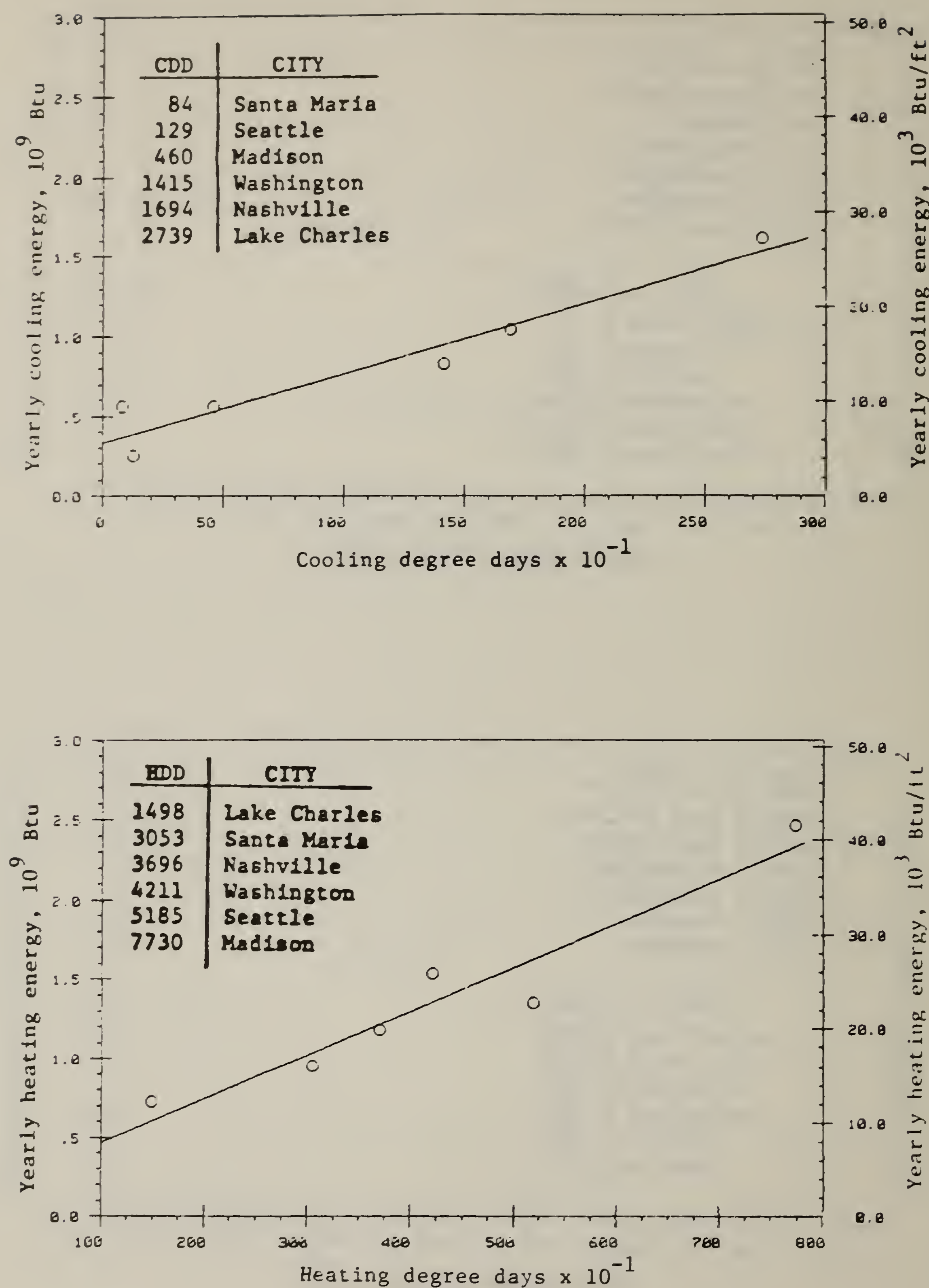
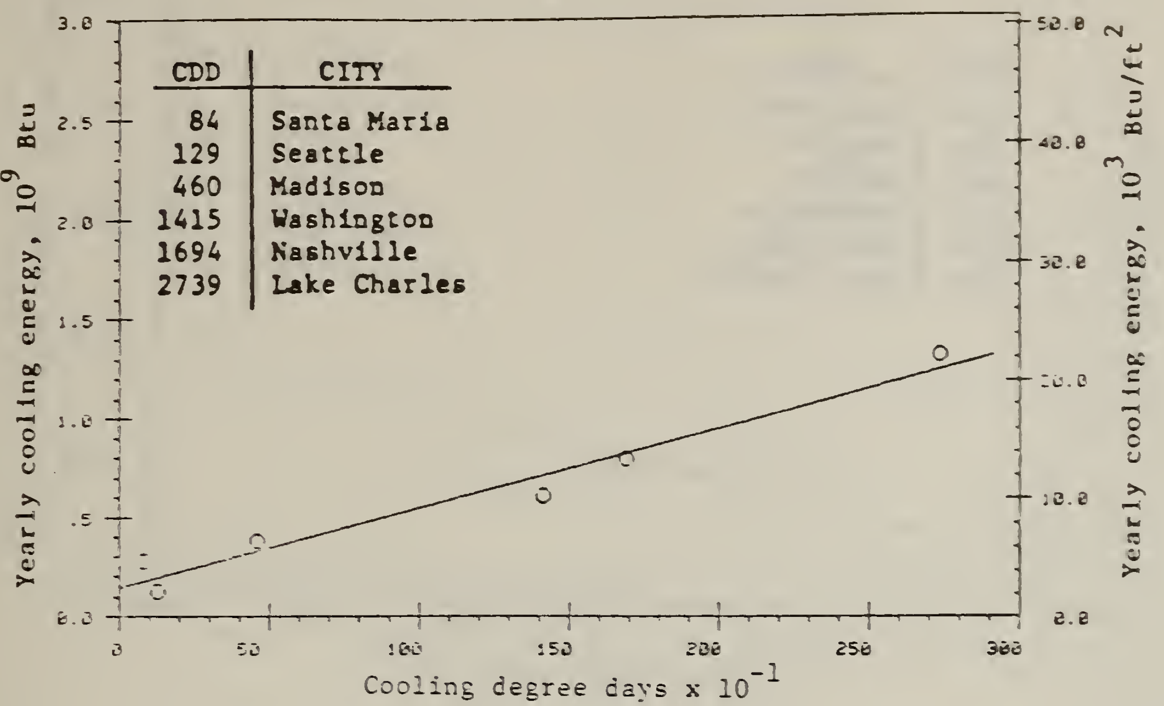


Figure 29. Cooling and heating energy consumption of case 18 (entire school) -- case 3 for classrooms and offices, enthalpy economy cycle for non-classroom/office areas



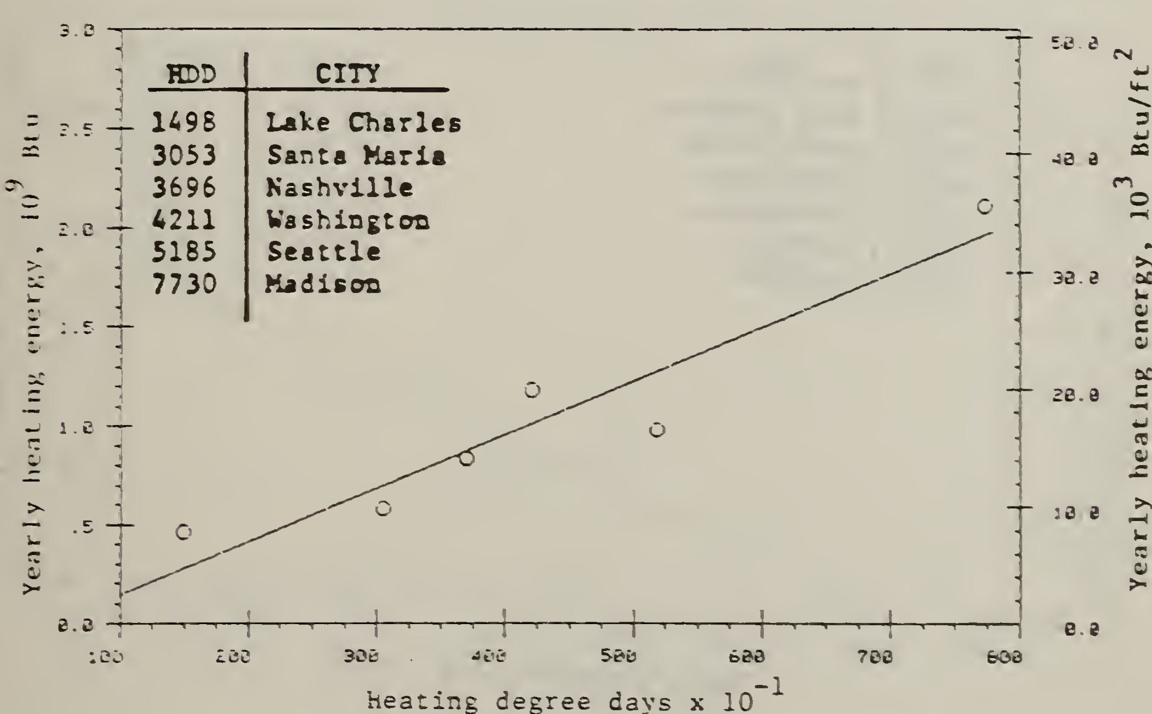
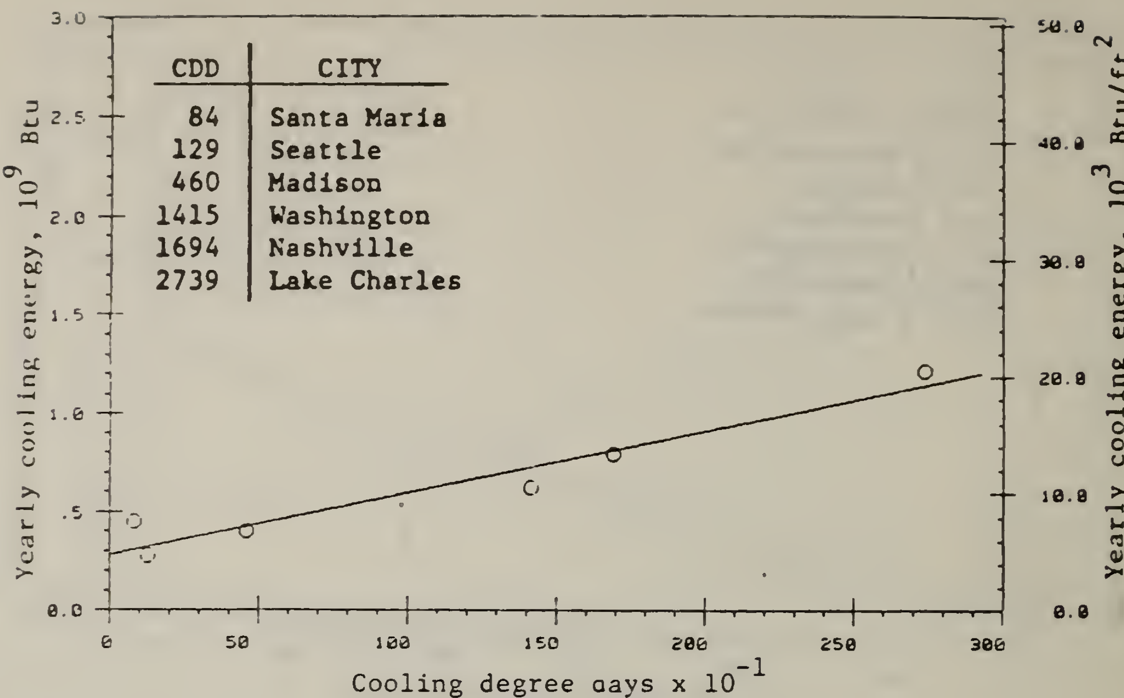


Figure 30. Cooling and heating energy consumption of case 19 (entire school) -- case 5 for classrooms and offices, enthalpy economy cycle for non-classroom/office areas



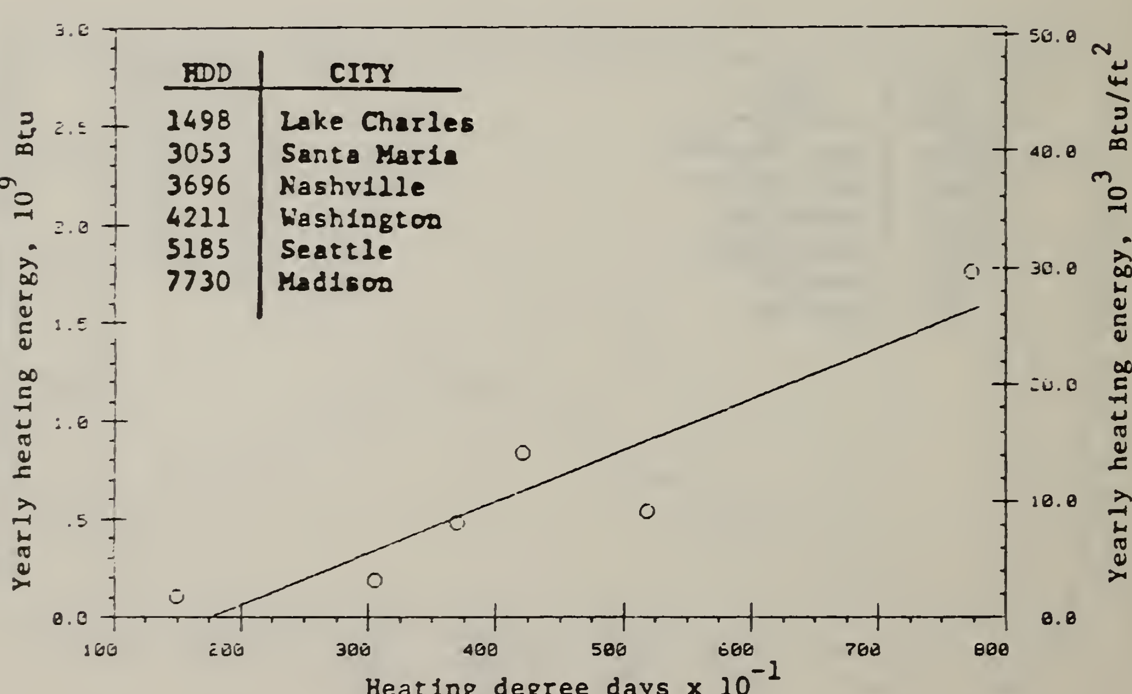
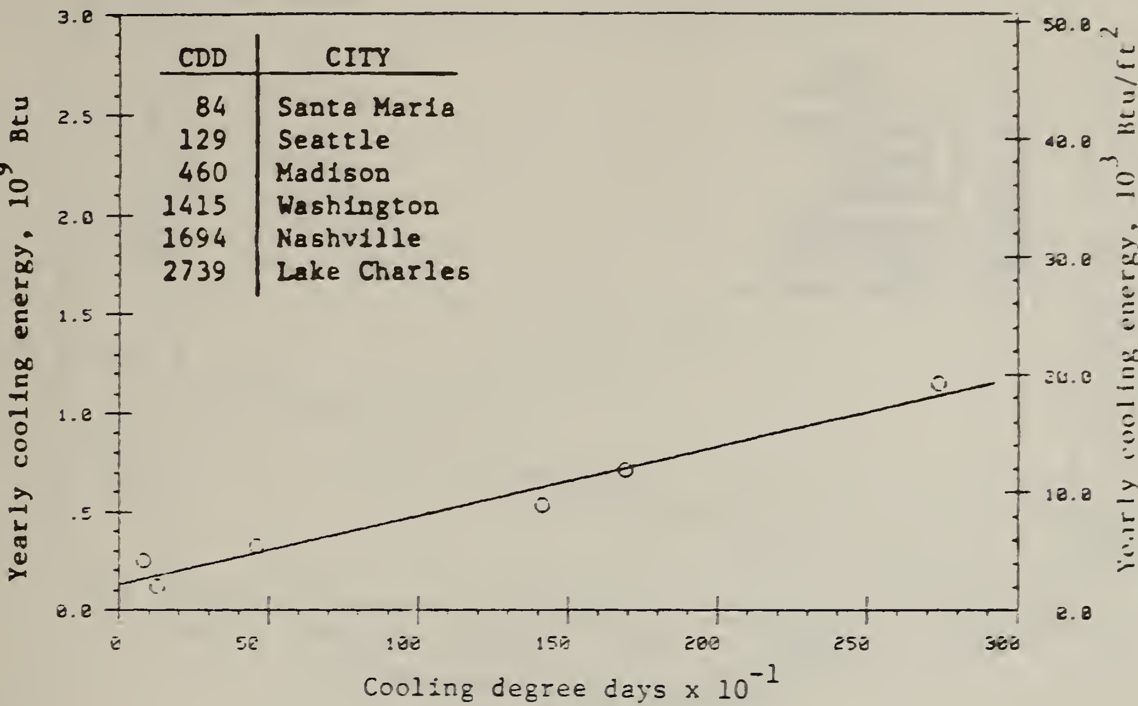


Figure 31. Cooling and heating energy consumption of case 20 (entire school) -- case 6 for classrooms and offices, base systems for non-classroom/office areas



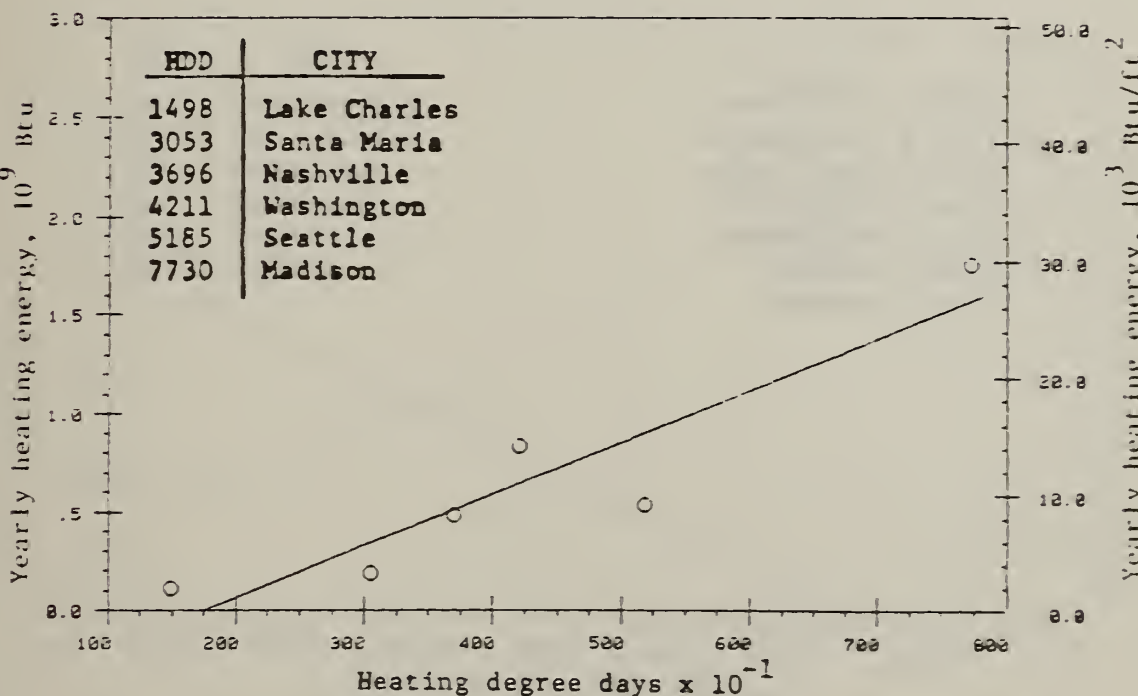
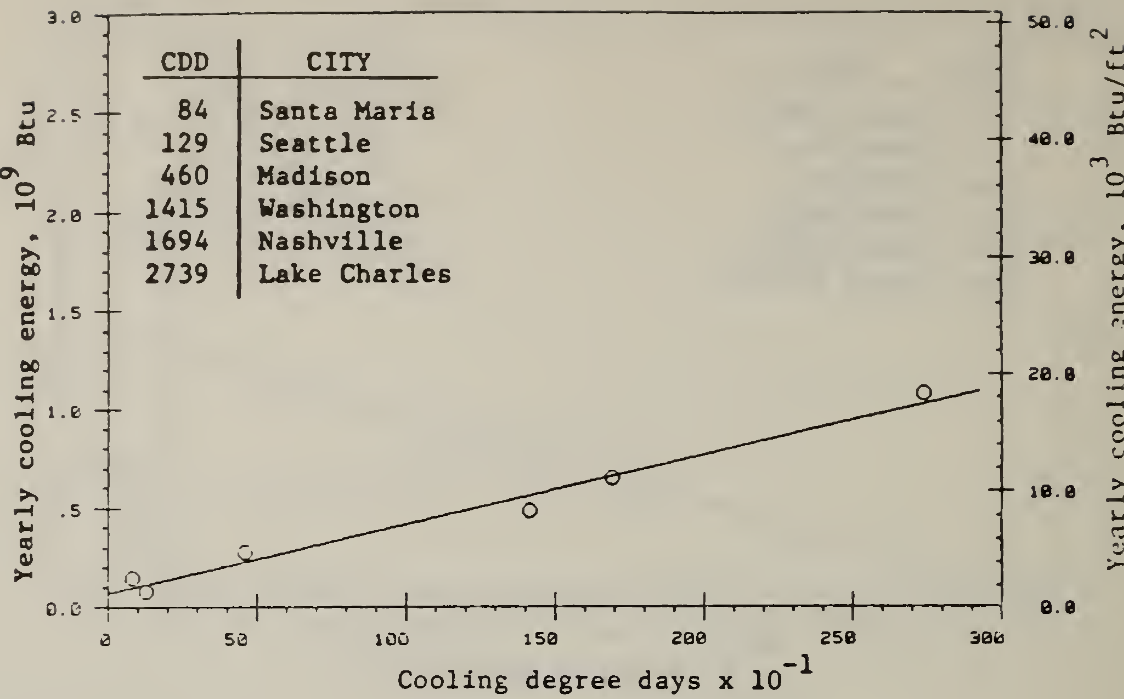


Figure 32. Cooling and heating energy consumption of case 21 (entire school) -- case 8 for classrooms and offices, enthalpy economy cycle non-classroom/office areas



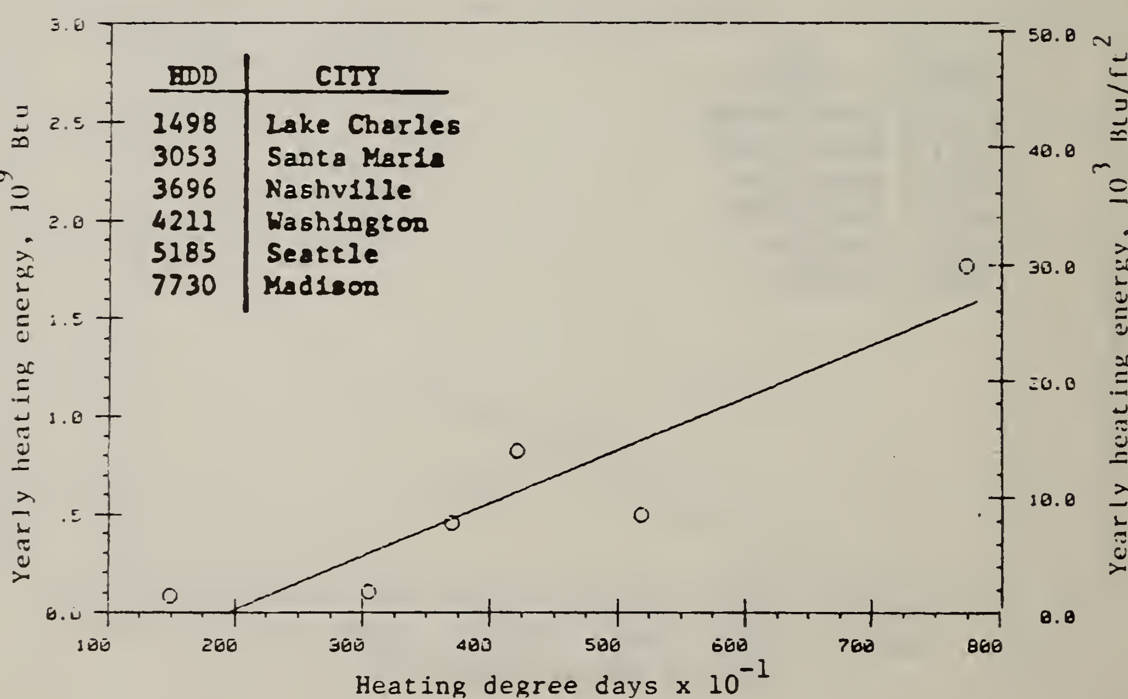


Figure 33. Cooling and heating energy consumption of case 22 (entire school) -- case 10 for classrooms and offices, enthalpy economy cycle for non-classroom/office areas

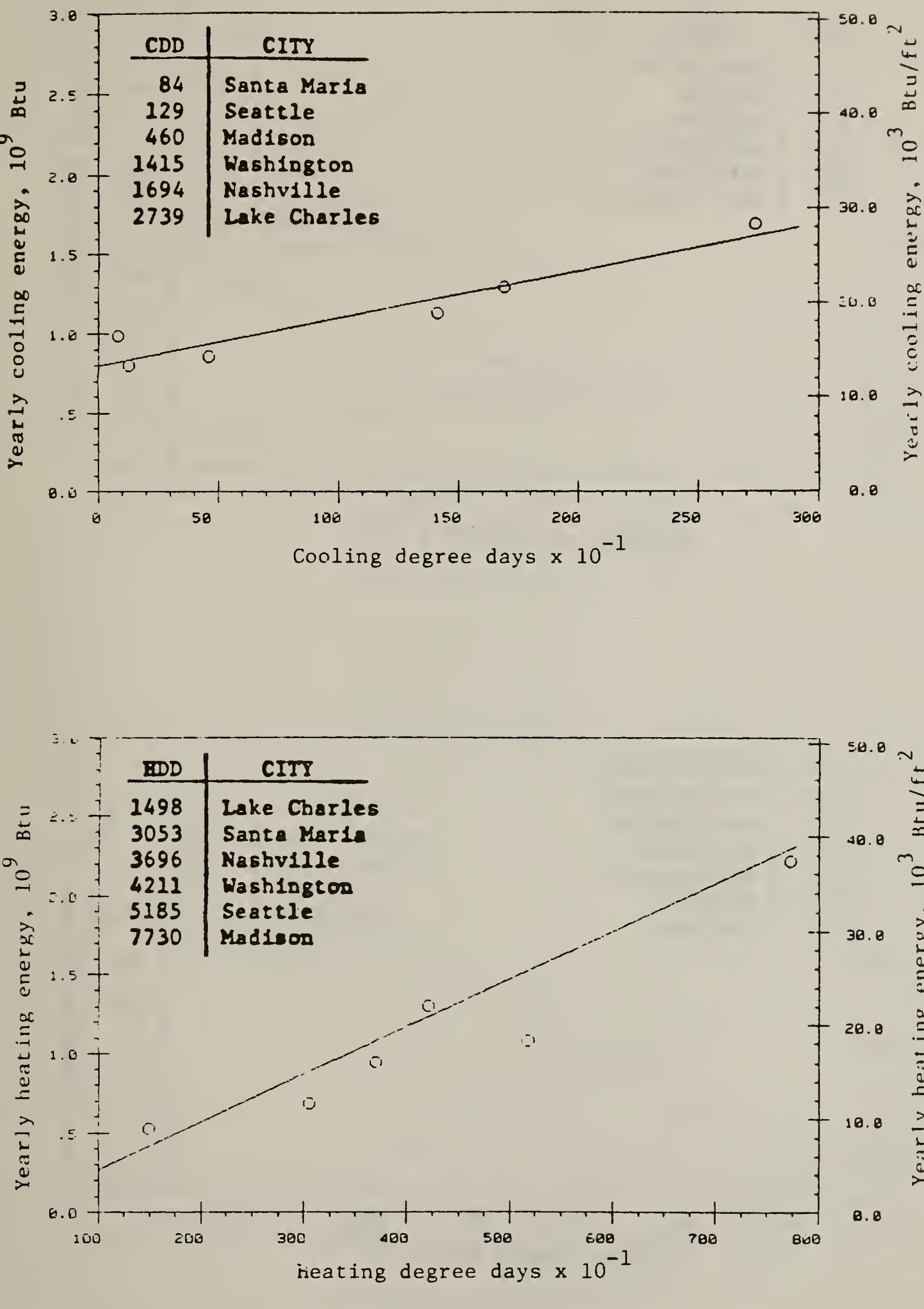


Figure 34. Cooling and heating energy consumption of case 23 (entire school) -- case 11 for classrooms and offices, base systems for non-classroom/office areas

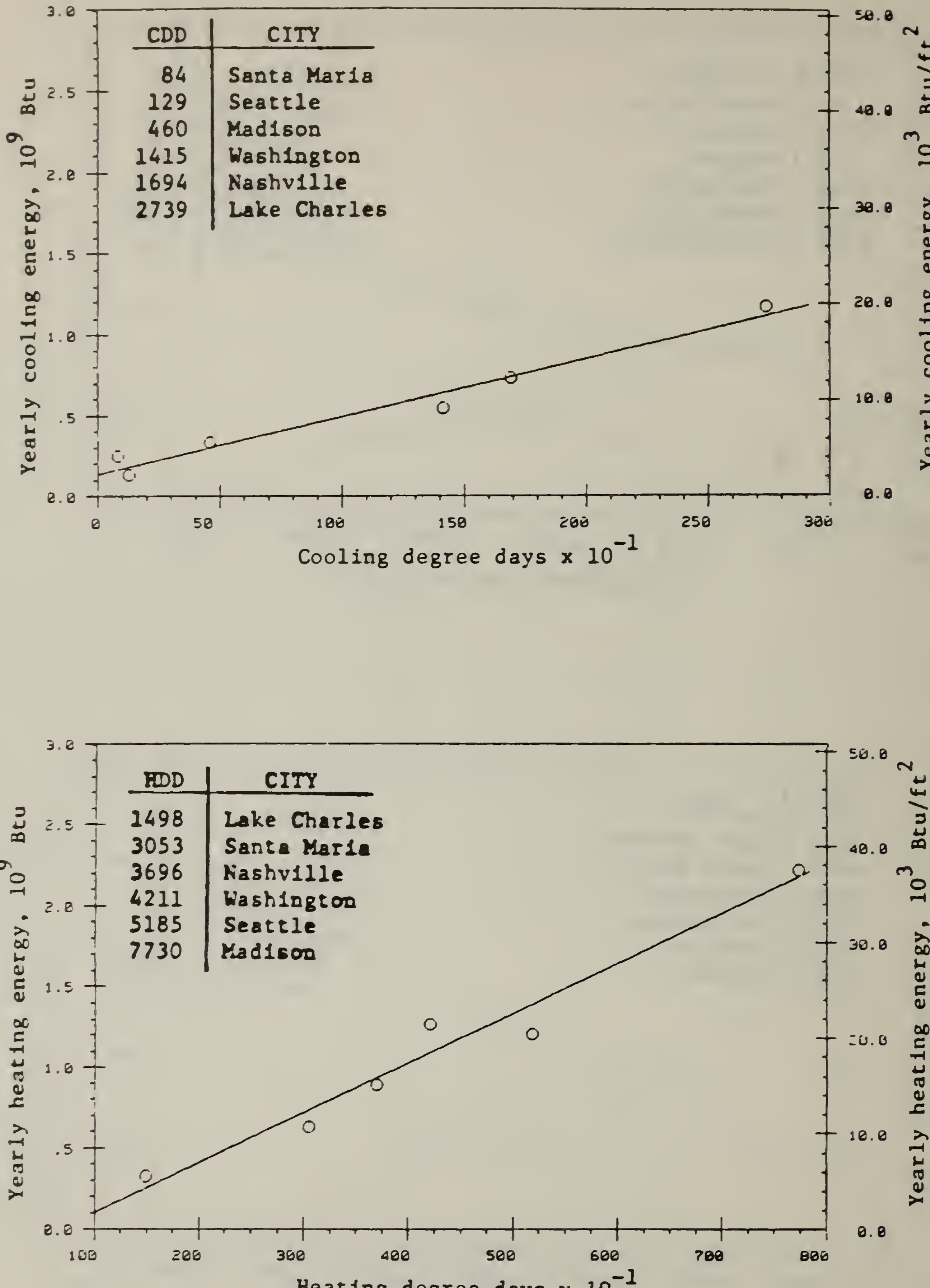
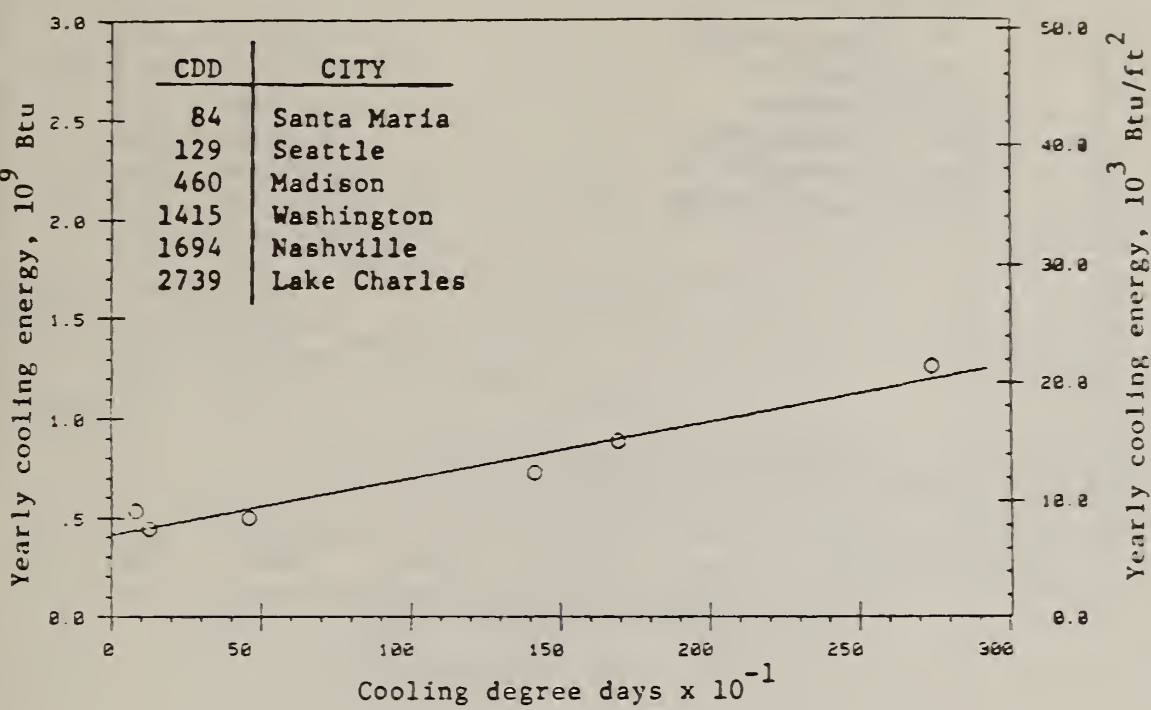


Figure 35. Cooling and heating energy consumption of case 14 (entire school) -- case 13 for classrooms and offices, enthalpy economy cycle for non-classroom/office areas



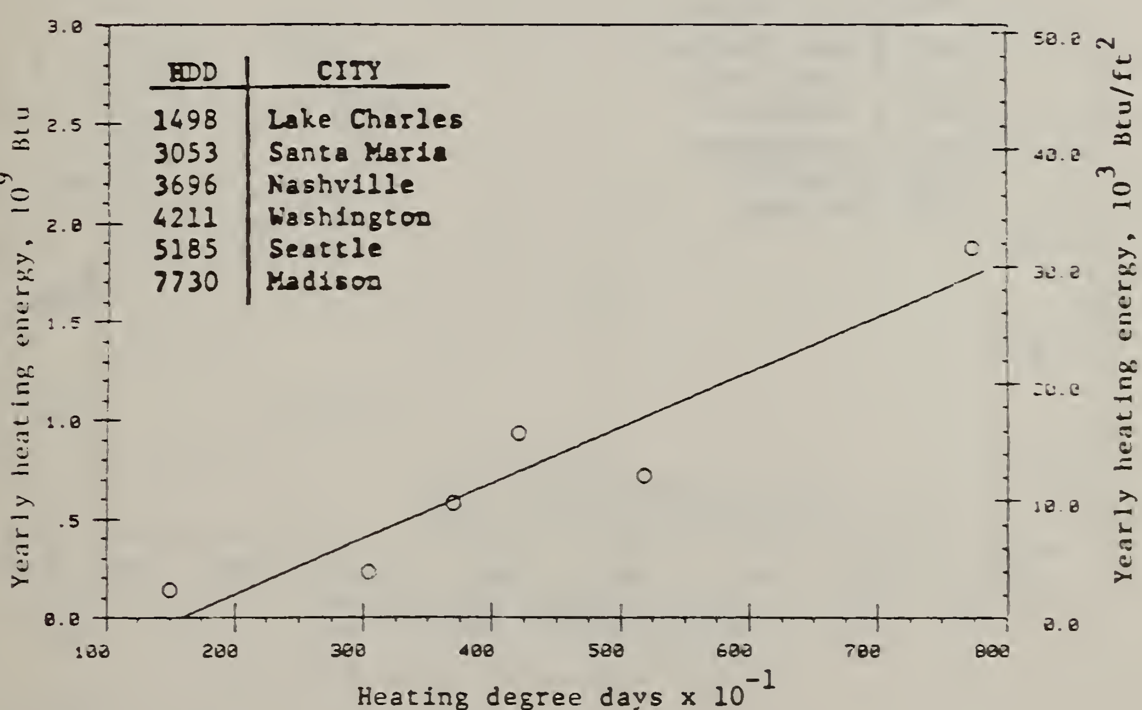
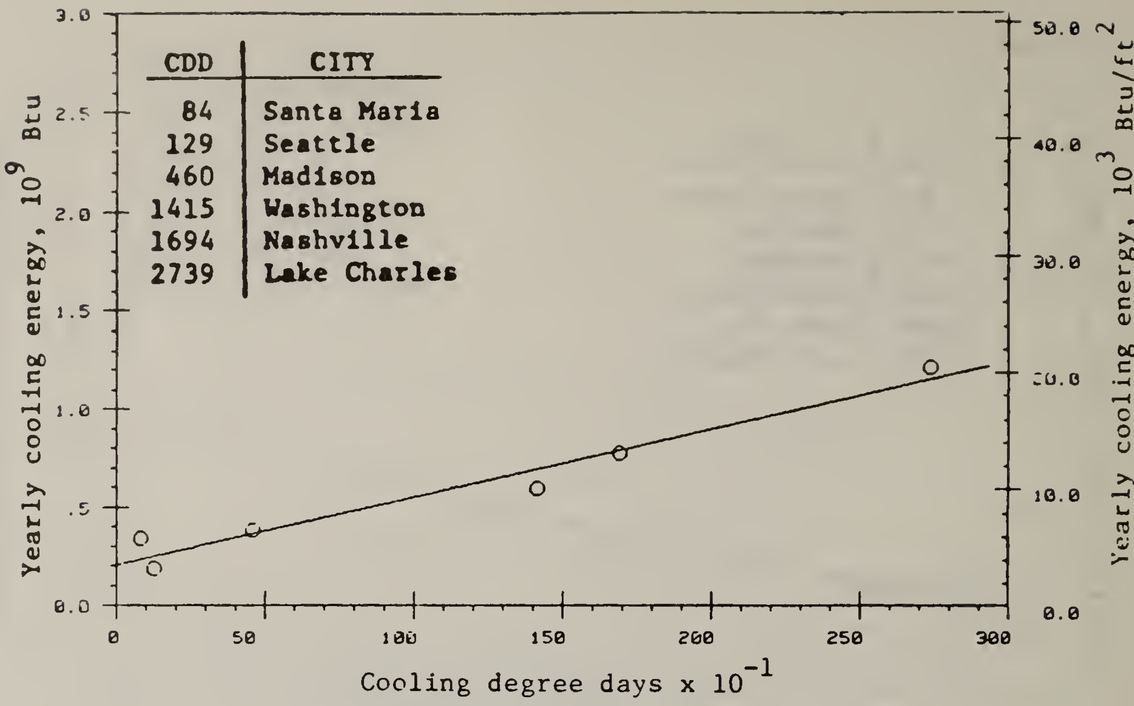


Figure 36. Cooling and heating energy consumption of case 25 (entire school) -- case 14 for classrooms and offices, enthalpy economy cycle for non-classroom/office areas



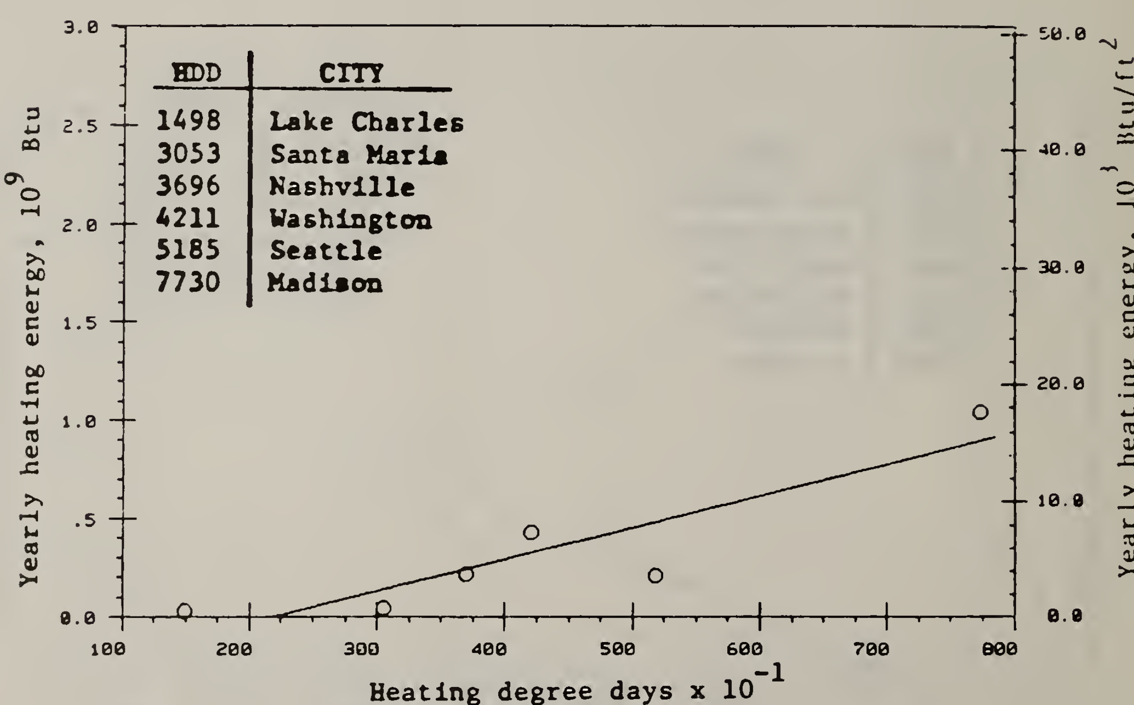
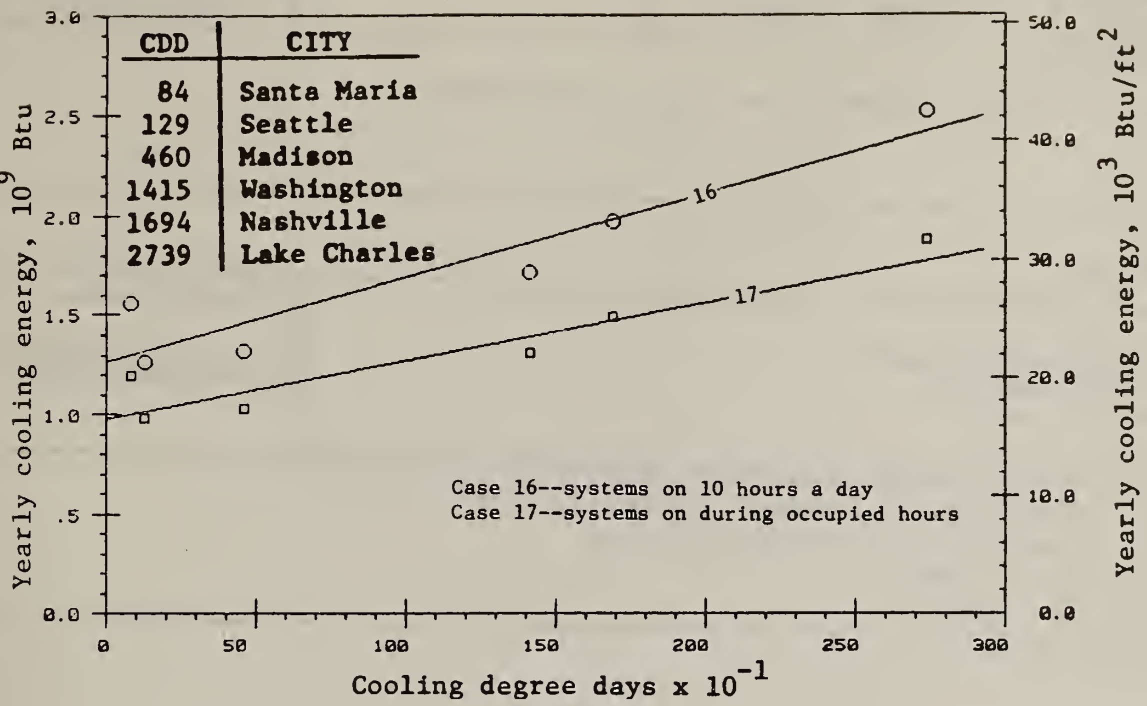


Figure 37. Cooling and heating energy consumption of case 25 (entire school) -- case 15 for classrooms and offices, enthalpy economy cycle for non-classroom/office areas



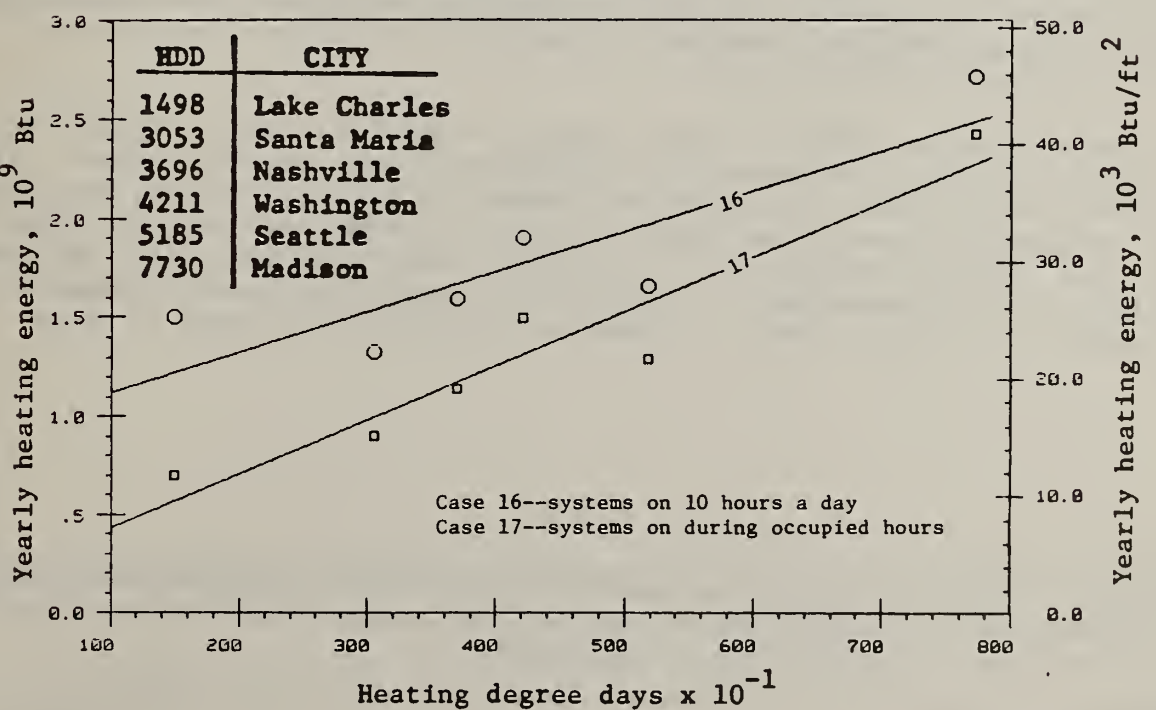


Figure 38. Cooling and heating energy consumption of cases 16 and 17 (entire school)

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A comparative analysis is made of the thermal performance of selected HVAC systems and control strategies commonly employed in education buildings. The comparisons are made for six geographical locations representing wide climatic variations within the continental United States.

Hour-by-hour simulations with the BLAST computer program are used to obtain the yearly heating, cooling, and fan energy consumption of an elementary school. The HVAC systems simulated are constant volume reheat, variable air volume, dual-duct, and unit ventilator systems. The control strategies tested are dry-bulb temperature economy cycle, enthalpy economy cycle, supply air temperature resetting, and the combinations of these strategies. The results of these simulations are presented and discussed. Substantial energy consumption differences are shown to exist.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

school building control strategies; school building energy conservation; school HVAC systems; school building thermal performance.

13. AVAILABILITY

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